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SEPTEMBER, 1956

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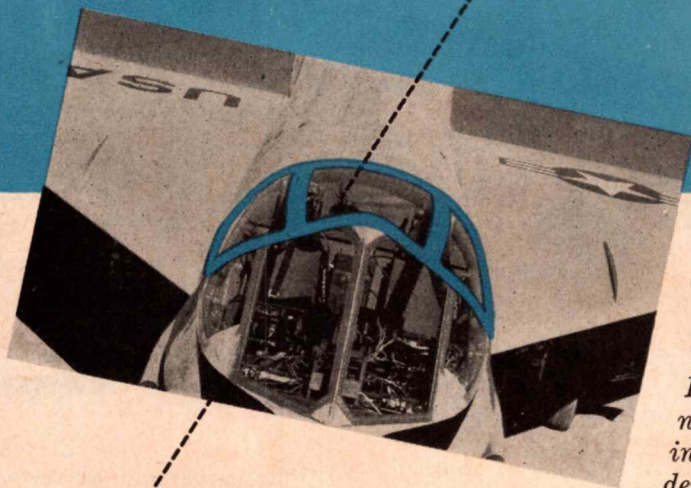
This dramatic demonstration of pilot and crew proficiency was made possible by C-123 maneuverability, short field performance and utter reliability—all three, features of Fairchild aircraft designs.

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The sighting panels of the TF-102A, the combat proficiency trainer version of Convair's F-102A interceptor, are now being produced in Swedlow's recently developed stretched acrylics.

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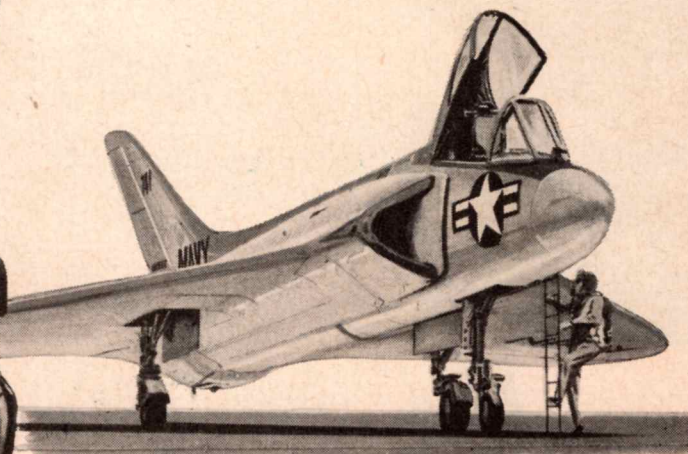
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Sprints from deck to stratosphere

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Douglas F4D Skyray—fastest carrier-based interceptor. Performance of agile Skyray continues the Douglas tradition of "faster and farther with a bigger payload." Yet performance figures are meaningless without a skilled pilot at the controls. If you are interested in a career as a Naval Aviator, write Nav. Cad. Washington 25, D. C.

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AERO DIGEST

AVIATION ENGINEERING

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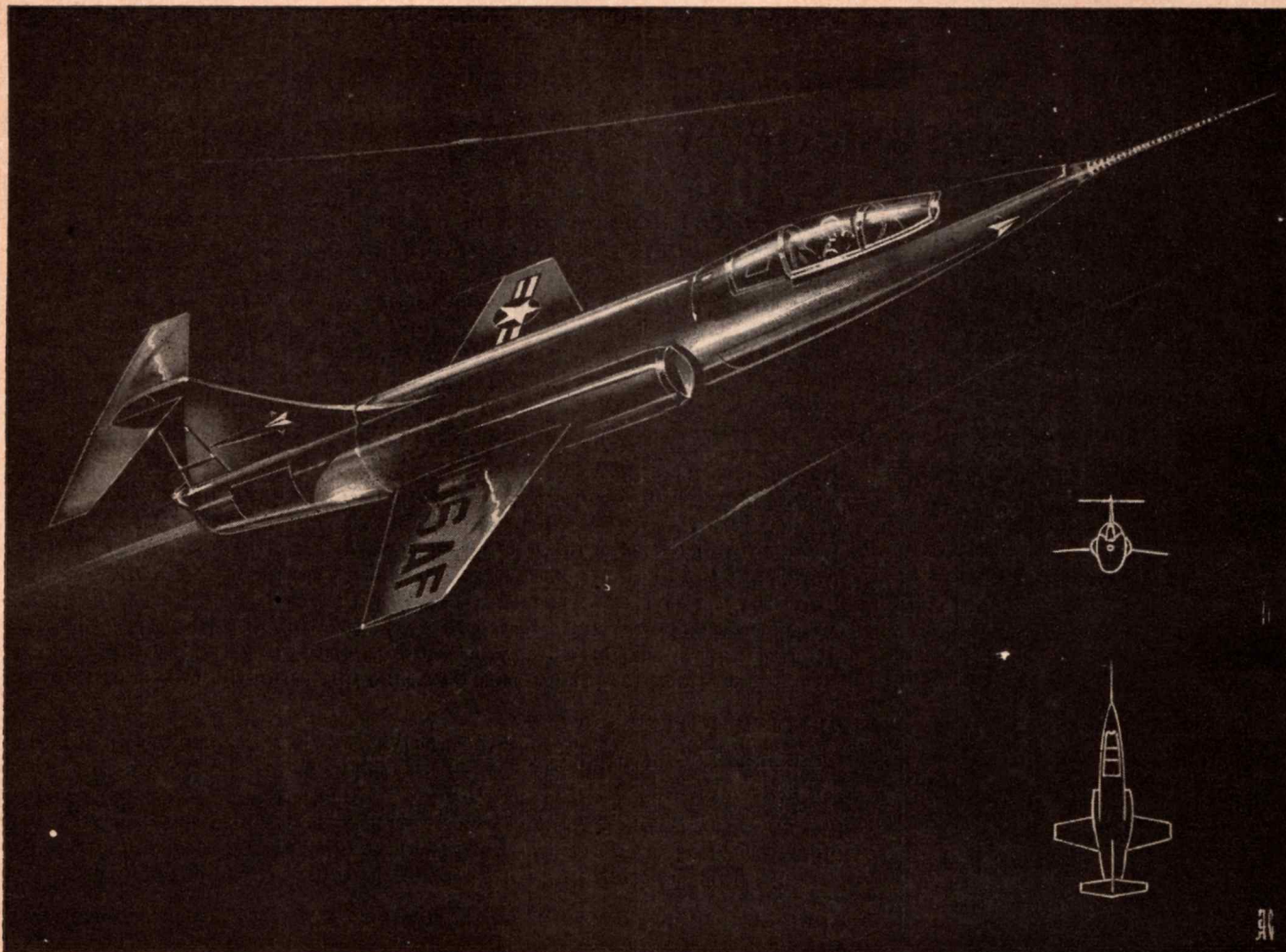
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The F-104A Starfighter is powered by the new J-79 turbo-jet engine with afterburner. At top speed, this en-

gine develops half of its thrust as a ramjet. Operational altitude for the speedy fighter is the upper stratosphere.

Slices through air on razor-blade wings

Lockheed's new Starfighter is the fastest yet!

The keen leading edge of her wing — felt-covered to protect ground crewmen when the plane is not in flight — knifes through the air at lightning speed. General Nathan F. Twining once called the Starfighter "the fastest and highest-flying fighter anywhere in the sky."

The lightweight F-104A — like other modern jets — has many parts made with Inco Nickel and Inco Nickel Alloys. That's because these metals provide the special

combinations of heat resistance, corrosion resistance, strength, and ductility necessary for top performance under severe service conditions.

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Incoloy "901"	Fuel line tubing		
Turbine discs	Rivets		

For further information circle Reader Reply No. 21

aero news digest

News in Brief

UNDERWATER MISSILE: Look for one of the biggest outfits in the country to come up with cogent proposals for development of underwater-to-air missiles (AERO DIGEST, May 1956), despite the fact that none of the services have to date done any work in the field. The company in question is conducting intensive research of German findings in the field. Its engineers believe that current progress in electronics offers a golden opportunity to pick up the underwater project where the Germans left off, with a highly effective weapon as the result.

VERTICAL JALOPY: Although they are still vague about a price tag, Cessna Aircraft Company executives believe that the one on their four-place CH-1A helicopter will be enough in line to attract a strong market in the executive—and deluxe—lightplane field. If this proves true, it will herald a long-dreamed-of era in U. S. flying—a plane that will land and take off in its own garage space—an automobile of the air. The current version was certified for commercial use by CAA this spring, and deliveries are promised early in 1958. Army will get the first off the line for evaluation purposes.

SPEED: Although it has been known since late July that Lt. Col. Frank Everest set a new speed record in the Bell X-2 of over 1900 mph, most startling recent news in the speed field is that Lockheed's rocket test vehicle for the Air Force, the X-7 has gone well over the 2000 mph mark. How much faster the ramjet test vehicle will go is still held top secret.

NAVAHO: Best information is that speeds far in excess of this high mark are promised from the X-10, test vehicle in the intercontinental Navaho guided missile project. X-10's existence was made official by Maj. Gen. Donald N. Yates, Commander of the Air Research and Development Command Missile Test Center at Patrick Air Force Base, Fla., where tests are already underway. The vehicle is powered by two turbojets and is built by North American.

NUCLEAR PLANE IN '57? Chances are much better than 50-50, according to best available sources, that a nuclear powered plane will be flown before another year. Lockheed has a large force of engineers working on their project in Marietta, Ga., and, while silent on dates, reports "definite, concrete" progress. At United Aircraft, nuclear engine development is so far along that engineers are already being cleared for security to go to work on the production end of the job when ready.

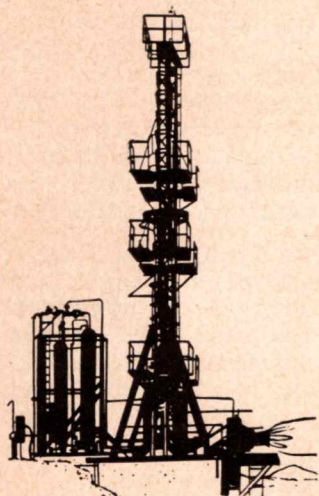
Rocket Powers British Canberra

The Napier Scorpion NSc. 1 rocket engine is being test-bedded in the belly of an English Electric Canberra. Early details on the liquid-propellant rocket installation reveal that the first ground runs in the

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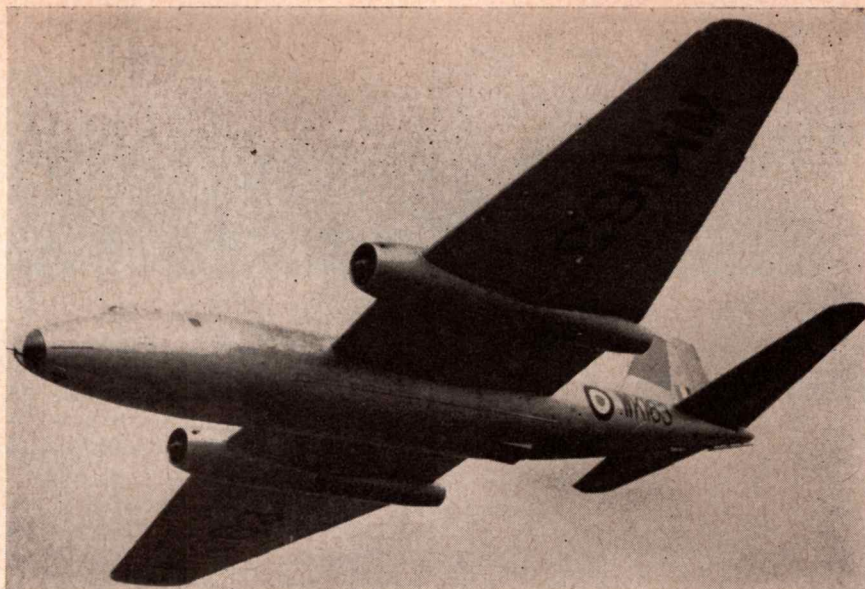
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Canberra test-bed for the Napier Scorpion NSc.1 rocket engine.

Canberra were made on May 19, and on the following day the first air-firings were carried out. Since then a series of firings have been run at a wide range of altitudes.

H-21 Helicopters Get Turbine Engines

Vertol Aircraft Corp. has been given a \$1.8-million go-ahead by the Navy Bureau of Aeronautics and the U.S. Army to equip two standard H-21C Workhorse helicopters with gas-turbine engines.

Contract for design, development, and test calls for installing two General Electric T-58 engines in each of two Army H-21C helicopters. Vertol president Don R. Berlin says that using twin-turbine powerplants, in place of the single engine now in use, will up the payload by 40 percent, and "will make possible cruising speeds of up to about 150 mph—50 mph faster than the current aircraft. This increase in cruise speed and payload will more than double the ton-miles per hour capability of the H-21. The hovering ceiling will also be increased by several thousand feet."

Men Wanted

"The starting salary range is up to \$15,000 (for engineers)," says Lycoming, Division of Avco Manufacturing Corporation in Stratford, Conn. The Company has immediate need for mechanical project engineers, installation engineers, transmission engineers and pneumatic engineers. Robert W. Stock will be glad to steer engineers' applications in the right direction.

Stroukoff Aircraft Corporation, West Trenton, New Jersey, is looking for design and layout engineers, aerodynamicists, systems analysts and stress men. The openings stem from the Corporation's new Air Force Contract for the YC-134 series, which will be the first support aircraft in the world to have both boundary layer control and pantobase all-surface landing gear. Man to write to for full employment data is R. C. Ward.

Joining in the recruiting action is the Bureau of Ships of the Department of the Navy, who wants to get them young and train them right. In an agreement reached



s'Gravesande's Stoomwagen

s'Gravesande's Steam Reaction Car

In 1721 Jacob Willem s'Gravesande of Delft, stimulated by the recently enunciated Third Law of Motion, astounded the Royal Society by constructing a practical steam reaction car.

The vehicle actually moved several times its own length, a distance of about two meters.

In 1956 the goal is no longer meters, but hundreds, and even thousands, of miles. Aerojet-General Corporation, leader in American rocket propulsion for more than a decade, is proud to participate in man's first assault on the frontiers of outer space—Project Vanguard.

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Aerojet-General invites scientists and engineers—men of imagination and vision—to join the attack on the most significant research, development and production problems of our time.

with the University of Maryland, the Bureau of Ships has arranged for a five-year work-study program for District of Columbia high school graduates. (They may be forced to do away with their geographic limitation.) Initially employed as GS-2 aides, selected students will spend five fall semesters and three spring semesters at the University, thereby completing a full four-year engineering program together with several periods at the Bureau of Ships. Participants enrolled in the program enter into a morally obligating agreement specifying that they will continue working with the Bureau for a five-year period upon completion of their training.

Czechoslovakian Trainer Revealed



Czechoslovakian Zlin 226 Trainer.

Aeronautical activities behind the Iron Curtain were glimpsed by AERO DIGEST European Editor R. A. Cole when he was recently allowed to examine the Czechoslovakian Zlin 226 Trainer. He reports that the airplane is basically a dual-purpose trainer suitable for either business or military use; it can also act as a glider tug. This is an important duty for East European aircraft since only non-powered flying is open to the public as a sport. It is a small craft with a span of 33.8 ft, length 25 ft and height 6.6 ft, while the maximum power available from the Walter Minor 6-III engine is 160 hp.

Fabric-covered, the airplane is structurally clean and boasts a welded steel-tube fuselage in conjunction with wing and tail surfaces of stressed-skin construction. All control surfaces are metal framed and fabric covered, and are of normal close-fitting type. Ailerons are mass balanced but not slotted. Wing has a tapered platform; sections used are NACA 4418 at the root and 4412 at the tip. This change, combined with a 3° washout and flow disruptors on the center-section leading edge, assures that stalling begins on the inner wing.

Tandem seating is provided for the two occupants by way of a long glazed canopy which slides back to allow entry and exit. Full dual controls and duplicated instruments are provided. Both the seat and rudder bar positions are adjustable. The engine is an inverted inline, 6-cylinder air-cooled unit. It drives a wooden fixed-pitch propeller which has unusually wide chord blades. Maximum engine speed is 2500 rpm; judging by sound, experts believe that the prop shaft is not geared. Oil is pumped to and from a reservoir in the port wing leading-edge where a small slot admits cooling air to the tank surround. The carburetor allows continuous inverted flying.

No effort has been spared to get a sturdy machine. To show the structure's integrity, pilots demonstrated sustained inverted looping, flick rolls and sharp pull-ups. A tailwheel-type undercarriage has cantilever main legs attached to the wing; these are sprung by oleo shock absorbers.

There are sub-versions of the design that allow the makers to offer aircraft that cover a wide-range of applications. Of these aircraft, the heaviest weighs 1800 lb loaded; at 70 percent power it will cruise at 124 mph, increasing to 142 mph at full power. Stall is at 46 mph, and a landing, using flaps and brakes, needs 465 feet. Initial rate of climb is 1000 fpm. A lower-powered version, having possibly not more than 130 hp available, has a much lower performance but it costs less—only \$6800 as against \$10,000 for the heavier airplane. Considering the finish and the equipment installed



Zlin 226 undercarriage leg.

in the craft, observers agreed that neither the British or American industries would be able to offer the aircraft at any smaller price.

F-105 Tagged "Thunderchief"

The supersonic, nuclear-weapons-carrying F-105 has been officially christened the Thunderchief. New name for the fast fighter-bomber was selected by Republic and approved by USAF. The F-105, which shattered the sound barrier on its first flight, is beginning to enter production at the Farmingdale plant of Republic. The aircraft has short, thin swept-back wings and a long cylindrical fuselage. Air to feed its powerful turbojet engine is received through wing-root intake ducts, permitting radar equipment to be installed in the needle nose. A one-piece flyig tail (stabilator) is set low on the aft section of the fuselage, on the underside of which is a ventral fin to provide lateral stability.

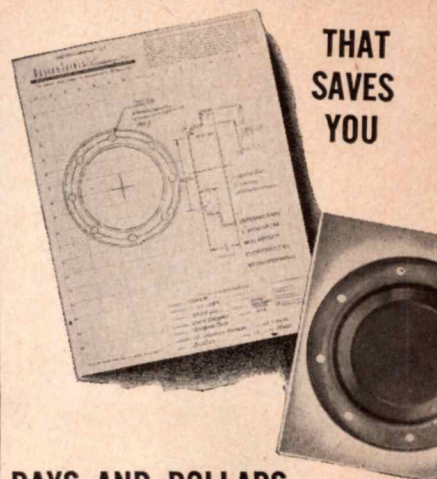
A3D Skywarriors Given Landing Chutes

A landing deceleration parachute designed to help reduce rollout of the Navy's largest carrier-based bomber, the Douglas A3D Skywarrior, is now being fitted to all production A3D aircraft. The chute is to be used for landing on airfields only and is not intended for shipboard use. Installation of the chutes followed an extensive testing program at Edwards Air Force Base carried out jointly by the Douglas company and the U. S. Navy. The husky 70,000 pound twin-jet bomber has low-speed landing characteristics and a Hytrol non-skid braking system that will normally stop the aircraft in a short distance. Addition of the deceleration chute, which measures 24 feet in diameter, will assure safe landings on wet runways, during instrument landings made under GCA conditions, or emergency landings made with high gross weight. The system is designed for normal touchdown speed of 150 knots and an emergency speed of 170 knots.

Names In the News

J. E. RHEIM, who for 16 years has been Executive Vice President, elected President and General Manager of Rohr Aircraft Corporation . . . New Chairman of the Board of Reaction Motors ,Inc. is WILLIAM C. FOSTER . . . ROGER TEWKSBURY named Chairman of the Board and T. S. BONNEMA President and General Manager of The Oster Manufacturing Company . . . Appointment of WALTER R. McLACHLAN as President of Orenda Engines Limited has been announced . . . Weber Aircraft Corporation has named ARNOLD JOHNSON Senior Vice President and FRED GODFREY Vice President—Manufacturing . . . Newly created position of Vice President—Operations at Solar Aircraft Company filled by WALKER G. DOLLMEYER . . . MARVIN B. RUFFIN is Summers Gyroscope Company's new Vice President General Manager . . . NORMAN WARREN, Director of Advertising and Public Relations for Lear, Incorporated was elected a Vice President . . . E. A. WILLIAMS appointed Vice President and General Manager of H. W. Loud Machine Works, Inc. . . . R. H. RICE, Vice President and a director of North American Aviation, named General Manager of the company's Los Angeles Division.

Here's the Magic SKETCHFORMING SET



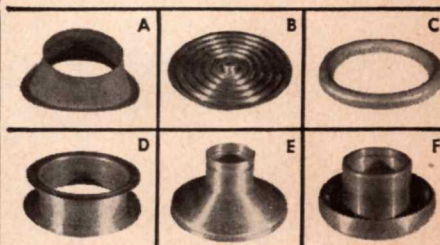
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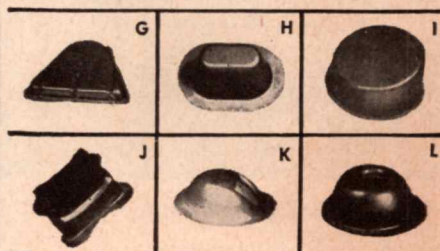
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METAL SPINNING AND SPINFORMING:

Typical items: A—Aircraft detail; B—Decorative cover; C—Retainer ring; D—Winding reel; E—Electronic shield; F—Electrical detail.

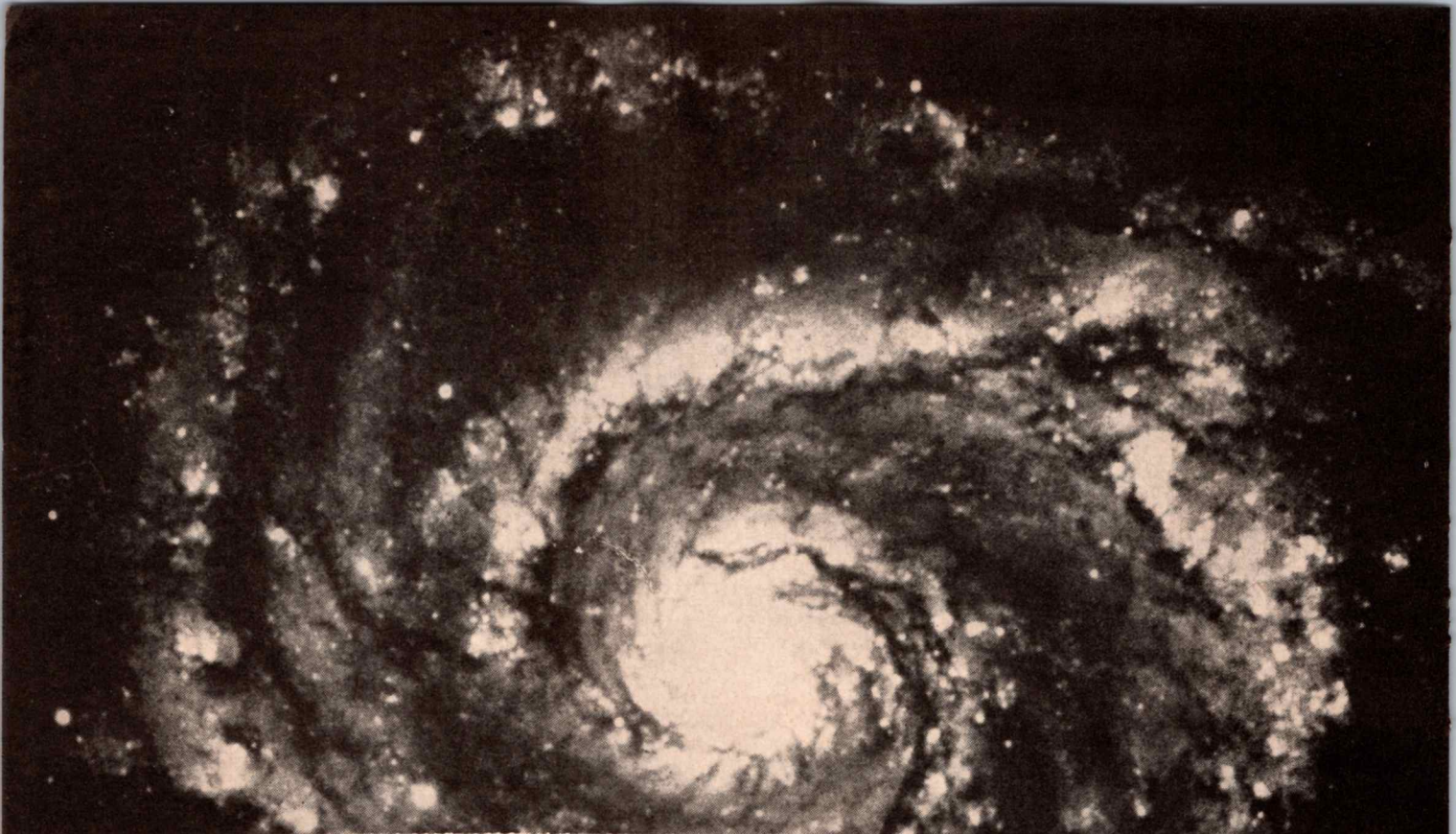


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Lockheed scientists are designing

WINGS FOR THE ATOM

Domesticating the atom to serve mankind has intrigued science for over a decade. One top priority application, secretly under way for several years at Lockheed: developing a nuclear-powered plane as different from present types as a supersonic jet is from the first stick-and-wire biplane.

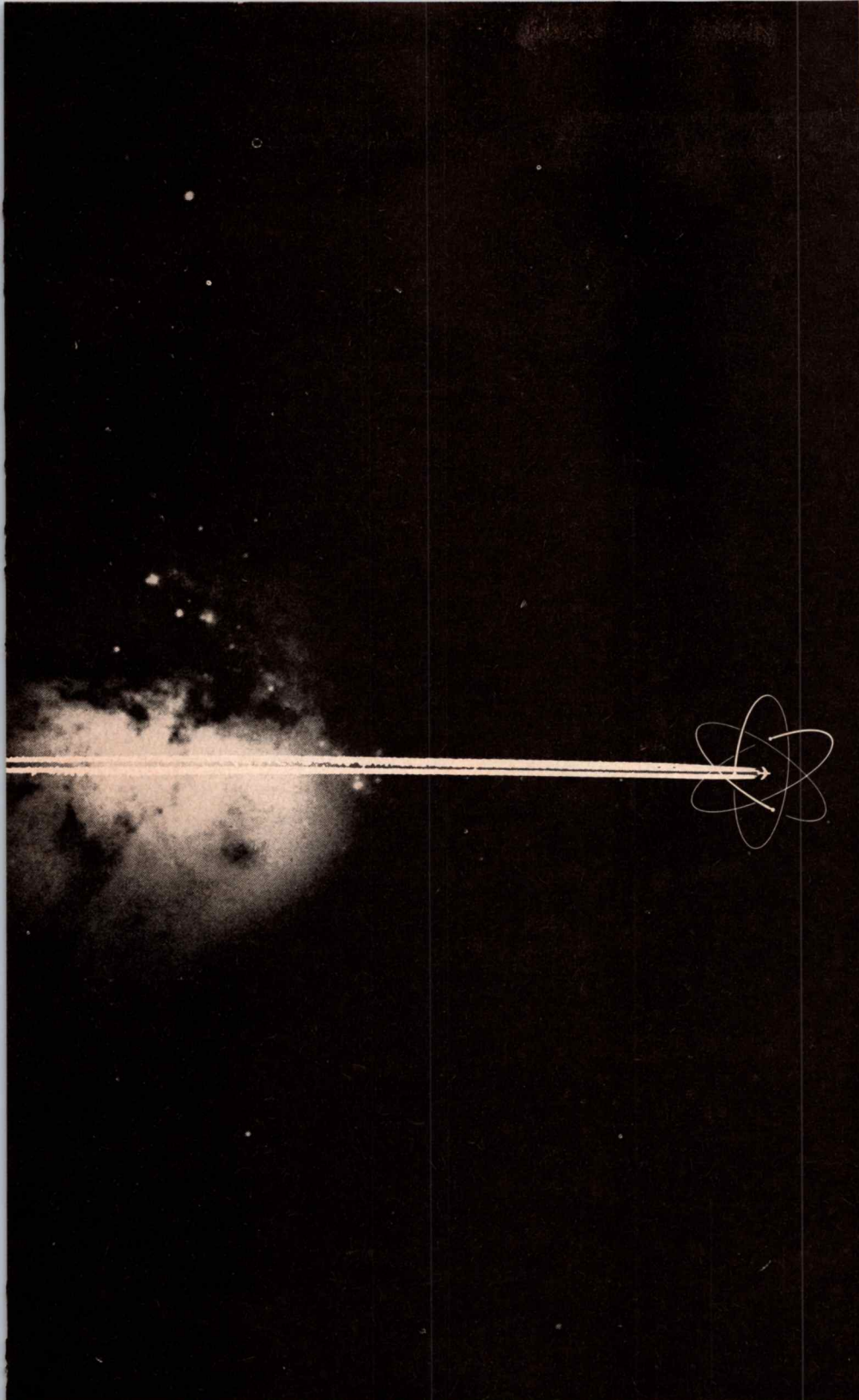
IMAGINE A GIANT AIRCRAFT SOARING ALOFT, NOT WITH TONS OF GASOLINE, BUT WITH A URANIUM FUEL SUPPLY NO BIGGER THAN A HANDFUL OF GRAVEL. EVENTUALLY, SUCH A PLANE-OF-THE-FUTURE—WITH THIS SCANT FUEL SUPPLY—WILL GIRDLE THE GLOBE NON-STOP BETWEEN SUNRISE AND SUNSET.

More than a dream, this incredible aircraft is now being developed by Lockheed for the U.S. Air Force despite problems of propulsion, structures and materials, thermodynamics, crew survival, producibility and maintenance unique in aviation.

Old concepts are being shelved, traditional solutions rejected. *The kind of aeronautical advances that once took a generation of research are now being telescoped into a few months, even weeks.*

Soon several hundred nuclear scientists and engineers from Lockheed's Georgia Division will move to the North Georgia mountain country. There on a vast site—some 40 miles from U.S. Air Force Plant No. 6 at Marietta, operated by Lockheed—will be built the nation's largest facility for the development of atomic-powered aircraft.

The exact status today of U. S. atomic plane



development is still a military secret. But the strategic importance of the "A-plane" to our nation can hardly be exaggerated. It will be an aircraft with a new dimension—endurance unlimited. Its immense range and round-the-world patrol capabilities are certain to revolutionize air logistics—freeing military aircraft from shackles presently imposed by fuel capacity and air-base location.

THE DAY WHEN AMERICA'S FIRST NUCLEAR-POWERED AIRCRAFT BECOMES OPERATIONAL WILL BE ONE OF THE TRULY SIGNIFICANT DATES OF AVIATION HISTORY.

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Palo Alto, and Sunnyvale, Calif.*

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Lockheed Aircraft Service, Ontario, Calif.

LOCKHEED'S NEWS COLUMN

Detection of Heart Disease—our nation's #1 killer—is being speeded with aid of Lockheed's battery of super-fast electronic brains that are correlating the studies sponsored by the Nash Cardiovascular Foundation. Ten minutes' work sandwiched between computations at the Missile Systems Division gives the cardiologist complete and accurate harmonic analysis of electrocardiograms that speed his vital research immeasurably...

Radiant heating, first time used in any airliner, will be one of the many new creature comforts of Lockheed's up-coming propjet Electra. Heating wires in walls and ceilings work like electric blankets to give no-draft, no-hot-spot comfort...

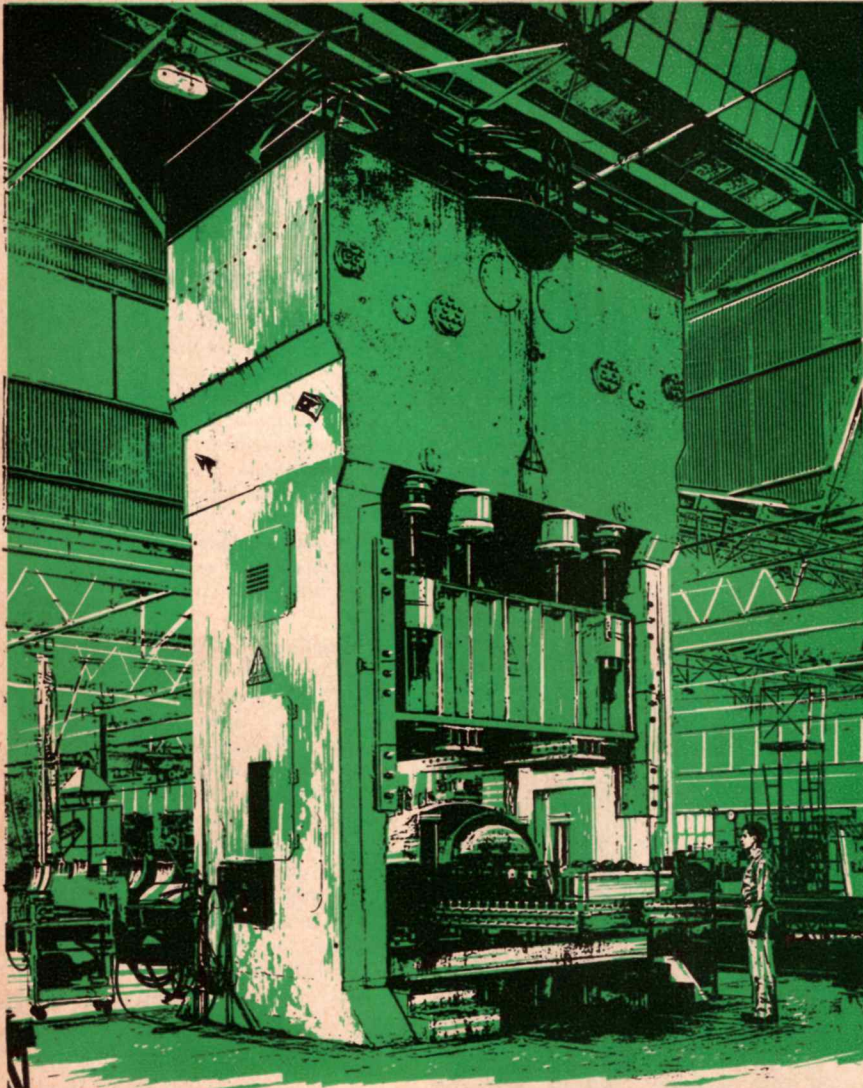
Atomic plane concept on a recent cover of Newsweek was *not* based in any way on Lockheed's Georgia Division ANP (Aircraft Nuclear Power) Project. That plane will *really* surprise you...

25,000 Lockheed stockholders in every state of the union learned in mid-August that sales reached approximately \$345 million for the first half of 1956. In a like period 20 years ago sales were less than *one* million...

Univac's newest cousin Si (for Scientific) will be the top quiz kid in the battery of analogue and digital brains at Lockheed's Missile Systems' Computer Center. Si, first Model 1103A Univac in use, "thinks" up to 100 times faster than other computers...

A nationally-known Los Angeles physician, after periods of intense nerve strain, goes to the airport, buys a round-trip ticket to New York on a Super Constellation, spends a quiet day at the Waldorf-Astoria, and comes back on the next flight. Says: "It relaxes me"...

Hercules C-130 performance data just released show that the USAF strong-man can haul 20 tons of cargo right on the contrails of a fast jet tactical force. 100 mph faster than present combat transports, Hercules climbs fully loaded to 2500 feet altitude in just one minute.



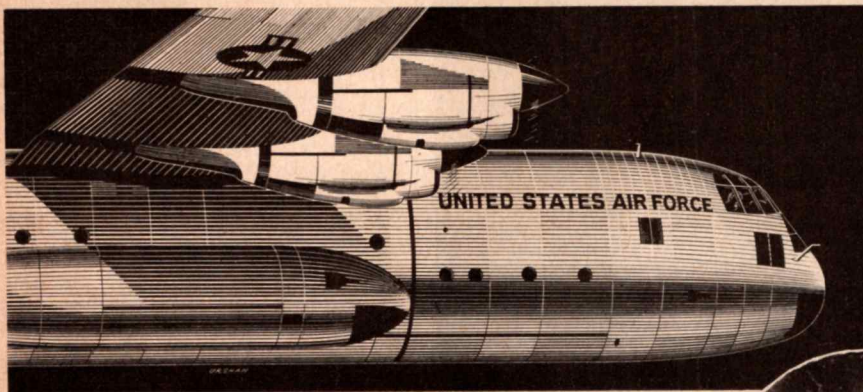
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This mighty press is one of the largest of its kind in the world. With its precision fingers it is particularly adapted to the delicate function of forming compound-contour skin sections for aircraft assemblies of many kinds.

Today, with this and hundreds of other heavy manufacturing machines, Rohr produces over 30,000 different parts for aircraft of all types. This is, of course, in addition to Rohr's being recognized as the world's largest producer of ready-to-install power packages for airplanes.

For design and engineering know-how, for full production facilities look to Rohr to build more into the aircraft parts you need.



In addition to the Lockheed C-130 Hercules shown here, Rohr builds power packages for many other leading commercial and military planes which have made Rohr famous as the

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Sept. 17-21—2nd Pacific Area National Meeting and Apparatus Exhibit, ASTM, Hotel Statler, Los Angeles, California.

Sept. 17-21 — International Congress on THEORETICAL PHYSICS, sponsored by National Science Foundation, National Academy of Sciences, ONR, Air Force Office of Scientific Research and University of Washington, Seattle, Washington.

Sept. 17-21—Instrument Society of America, 11th Annual INSTRUMENT-AUTOMATION Conference and Exhibit (International), New York City.

Sept. 17-22 — International ASTRONAUTICAL Federation, 7th Annual Congress, Rome, Italy.

Sept. 18-19 — Symposium on Technology of MOLYBDENUM and MOLYBDENUM BASE ALLOYS, sponsored by Engineering Society of Detroit, Rackham Memorial Building, Detroit, Michigan. (Further information from J. J. Harwood, Office of Naval Research, Washington, D. C.)

Sept. 24-26 — AMERICAN ROCKET SOCIETY Fall Meeting, Hotel Statler, Buffalo, New York.

Sept. 25-29—International Association of Aircraft Constructors, JET TRANSPORT Conference, The Hague, The Netherlands.

Oct. 1-3—12th Annual National ELECTRONICS Conference, Hotel Sherman, Chicago, Illinois.

Oct. 2-6—National Aeronautic Meeting, Aircraft Production Forum and AIRCRAFT ENGINEERING Display, sponsored by Society of Automotive Engineers, Hotel Statler, Los Angeles, California.

Oct. 7-9—3rd Annual AMERICAN HELICOPTER SOCIETY Western Forum, Adolphus Hotel, Dallas, Texas.

Oct. 8-9—2nd National Symposium on AERONAUTICAL COMMUNICATIONS, sponsored by IRE Professional Group on Communications Systems, Hotel Utica, Utica, New York.

Oct. 10-12 — Symposium to discuss JET ENGINE OVERHAUL Problems, sponsored by General Electric Company, Evendale, Ohio plant.

Oct. 25-26—Aircraft Electrical Society Annual Display of AIRCRAFT ELECTRICAL EQUIPMENT, Pan-Pacific Auditorium, Los Angeles, California.

Oct. 25-26—2nd Annual Technical Meeting of IRE Professional Group

on ELECTRONIC Devices, Shoreham Hotel, Washington, D. C.

Oct. 29-30—3rd Annual East Coast Conference on AERONAUTICAL and NAVIGATIONAL ELECTRONICS, sponsored by Baltimore section of IRE and IRE Professional Group on Aeronautical and Navigational Electronics, Baltimore, Maryland.

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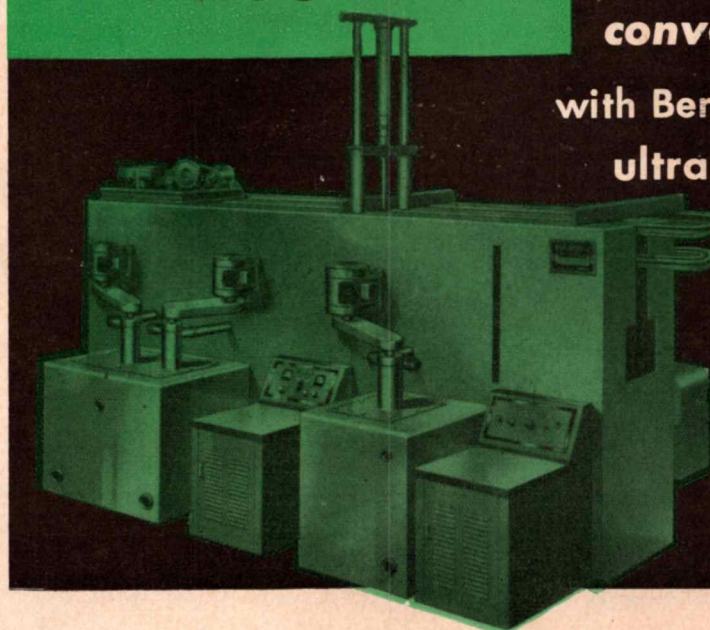
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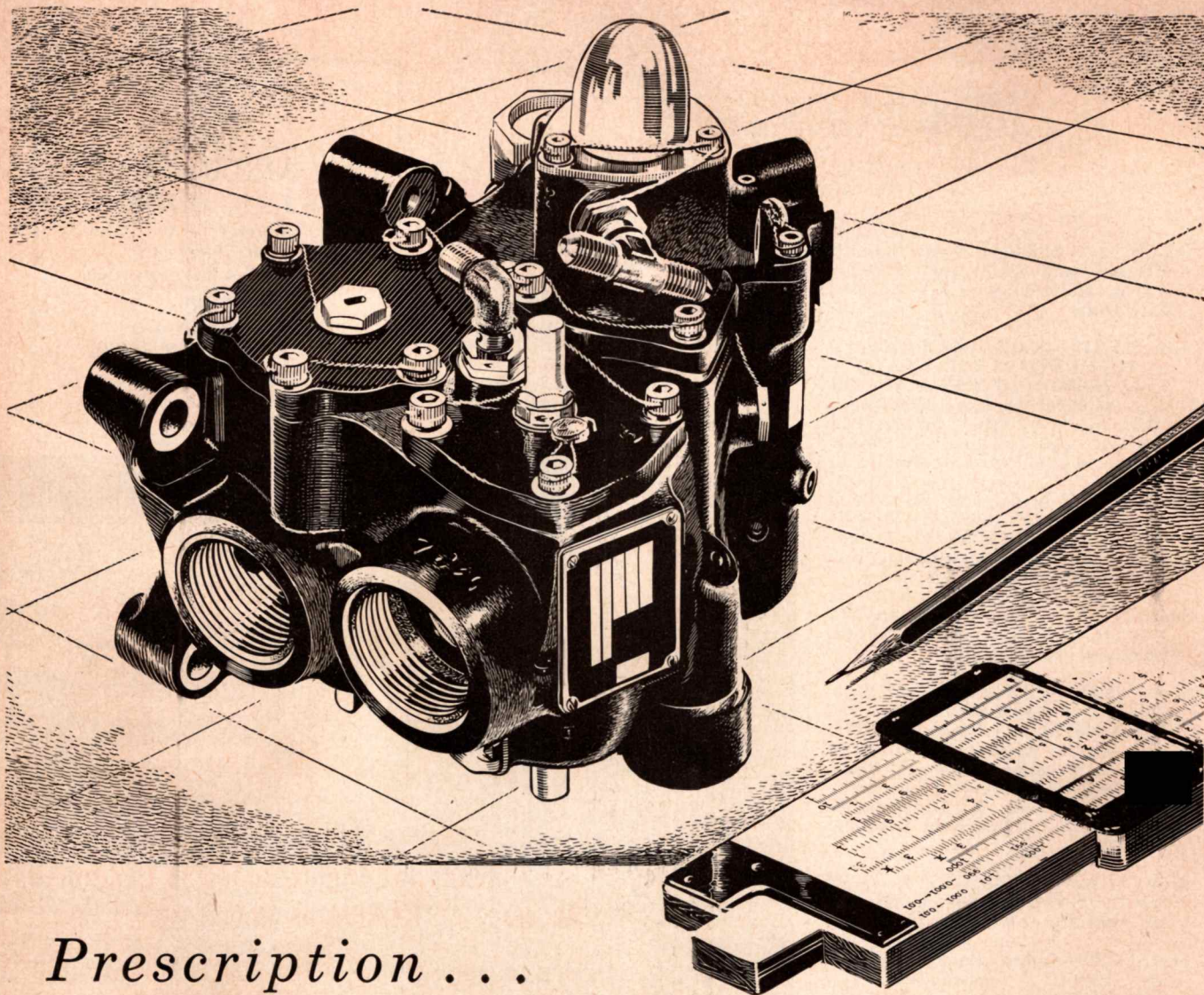
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new books

For further information circle number indicated under Trade Literature on Reader Reply Card — page 65

THE ANALYSIS OF STRUCTURES, N. J. Hoff, 1956, John Wiley & Sons, Ltd., New York. 493 pp, \$9.50.

The principle of virtual displacements is the starting point. The development of the minimal principles of structural theory is then presented. This is followed by a treatment of buckling phenomena. The book concludes with a section devoted to complementary energy and least work methods. Whatever mathematical methods beyond elementary calculus used are explained in enough detail to allow the reader to proceed without reference to other books.

Circle Reader Reply No. 90

ENGINEERING MECHANICS, fourth edition, S. Timoshenko and D. H. Young, 1956, McGraw-Hill Book Co., New York. 536 pp, \$7.50.

Ideally suited to the undergraduate courses given in engineering schools, this text will equip the student with a sound basic training in engineering mechanics and will acquaint him with as many general methods of attack as possible, illustrating the application of these methods to practical engineering problems.

Circle Reader Reply No. 91

THE UNITED STATES AIR FORCE DICTIONARY, edited by Woodford Agee Heflin, 1956, Air University Press. 578 pp, \$3. (For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D. C.)

Here is an excellent and much needed dictionary, professionally prepared and presented, and undoubtedly of value to anyone concerned with aviation or air power.

Circle Reader Reply No. 92

ATOMS AND ENERGY, H. S. W. Massey, 1956, Philosophical Library, New York. 174 pp, \$4.75.

This book gives a non-technical account of the developments in atomic physics which led up to the large-scale release of atomic energy. The similarities and differences between the atomic process that occur in ordinary combustion and in nuclear fission are explained in some detail in order to realize the immensity of the new power available.

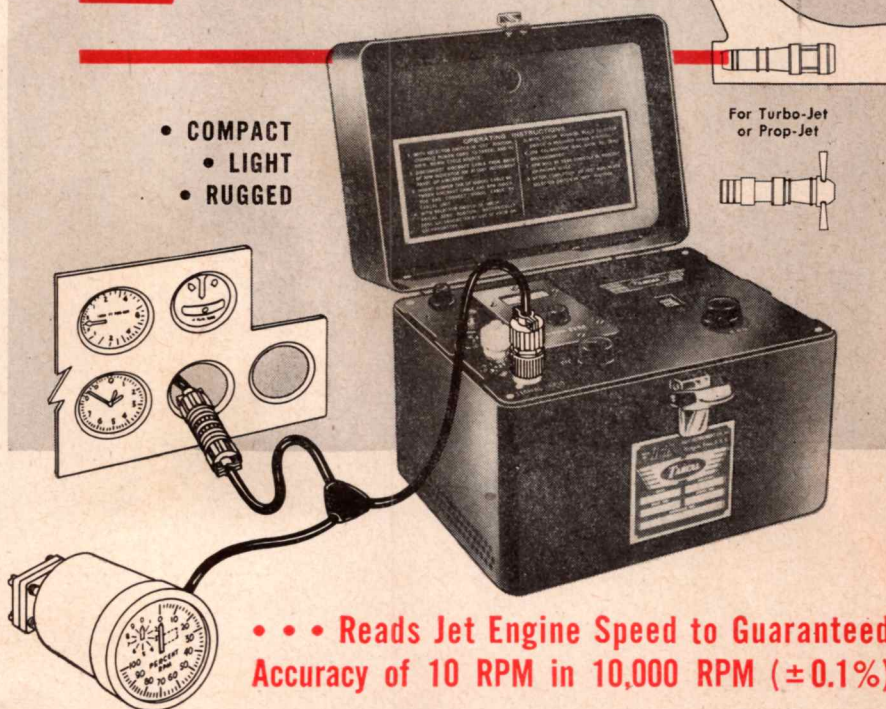
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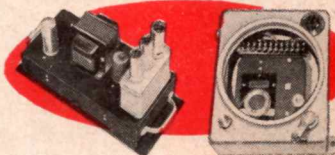
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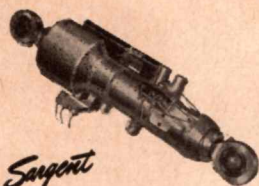


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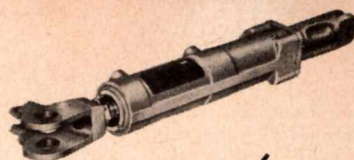
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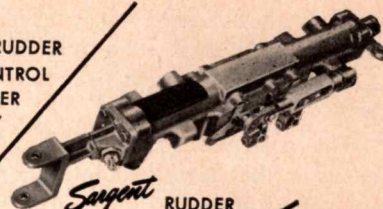
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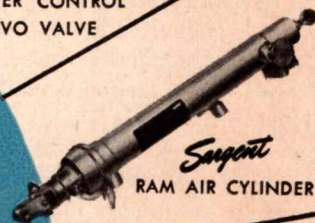
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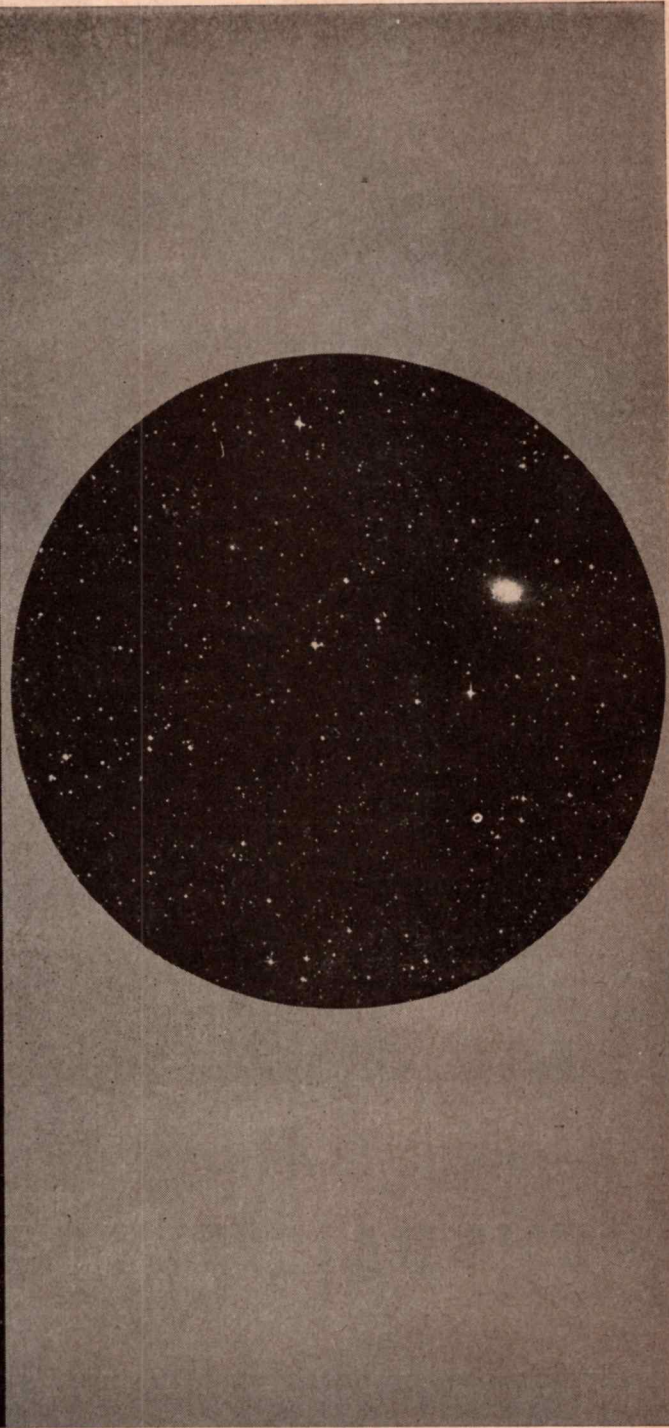
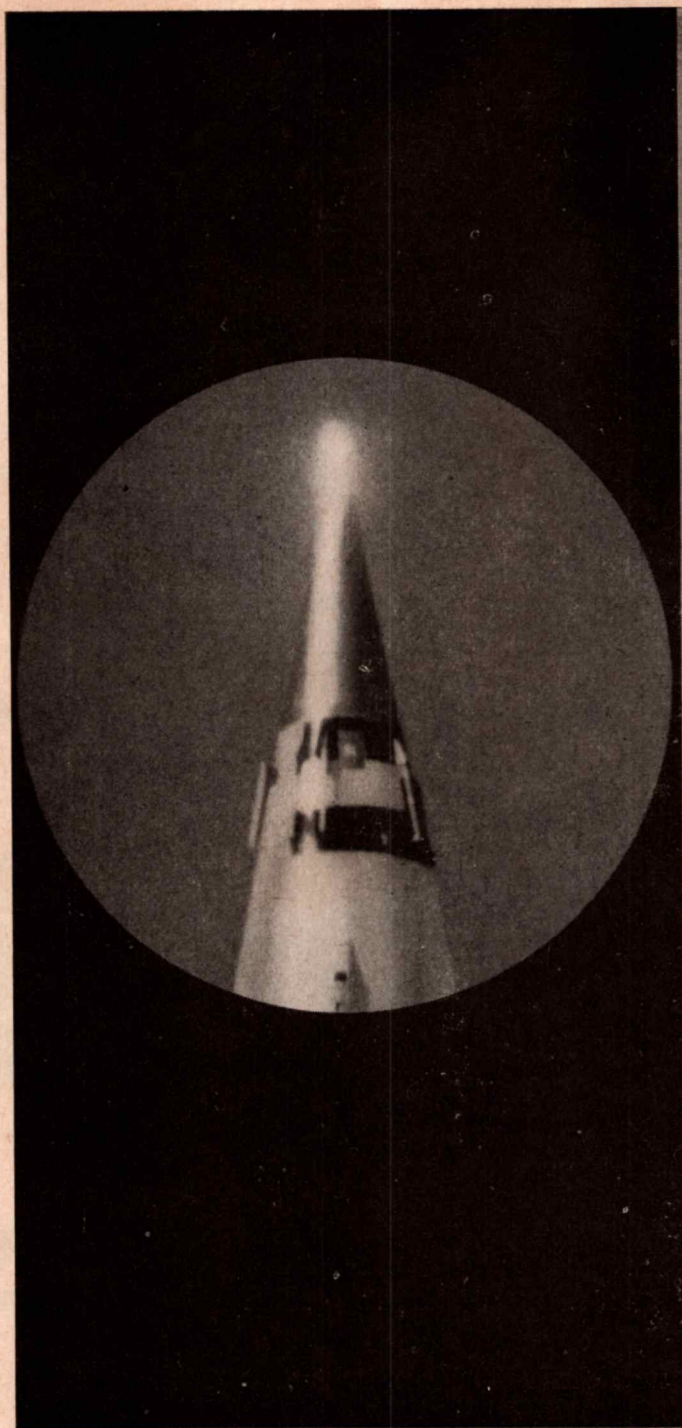
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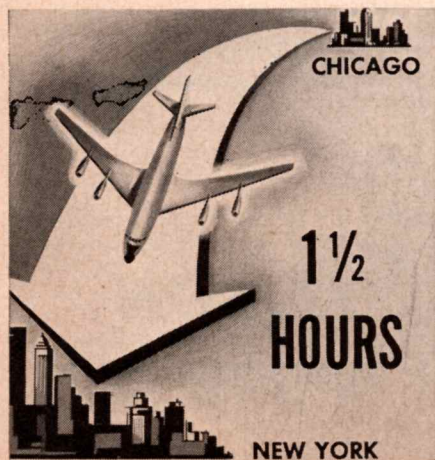
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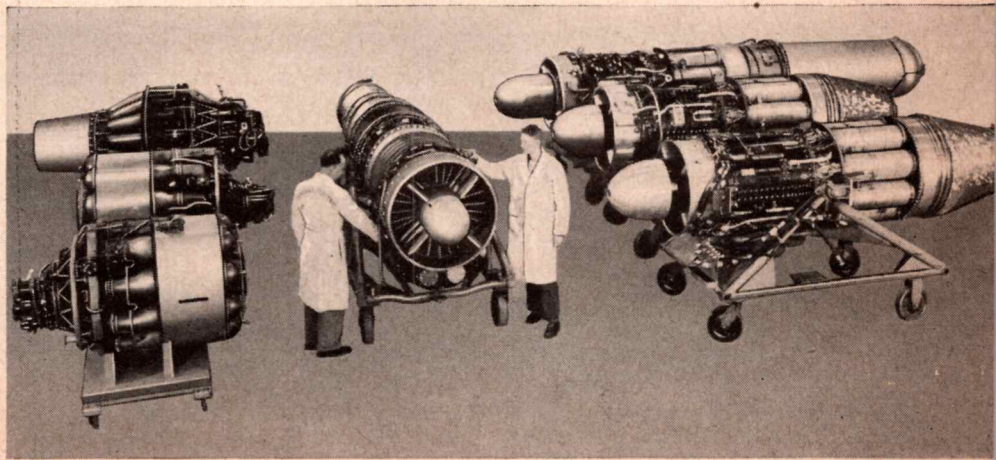
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AMERICAN BUILT FOR THE JET ERA IN AIR TRAVEL

For Further information circle Reader Reply No. 5

This paper is intended to acquaint aeronautical engineers in the United States with the contributions made by the aerodynamicists of the French O.N.E.R.A. to the subject of circulation control and its application to STOL aircraft. Circulation control is achieved in these studies by use of a full-span blowing jet of variable orientation located at or near the wings trailing edge.

Part of the information contained in this paper has been previously published in the proceedings of several scientific societies or in O.N.E.R.A. technical reports. Some of the material, however, is original. Roughly speaking, the paper represents the state of the art at the end of the year 1955. Since that time, work has been proceeding actively on both sides of the Atlantic. For example, Malavard has solved the three-dimensional problem of the lifting wing with trailing-edge blowing by making use of the electrical analogy method, and design studies of practical configurations incorporating circulation control have been completed.

The original manuscript of this paper was prepared by the French authors at the suggestion of the Air Branch of the Office of Naval Research, Navy Department, which has been following the progress of this research for several years. The presentation here represents the first opportunity to give the French work on circulation control a publicity equal to that received by its famous counterpart, the British "jet flap," which was presented in the AERO DIGEST issue of April 1956. The editors of AERO DIGEST are to be congratulated for making possible closer international scientific cooperation. It is hoped that the effect of this paper will be to stimulate further research and give impetus to an integrated powerplant-airframe program.

G. Boehler

Jet-Induced CIRCULATION CONTROL

L. MALAVARD

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P. JOUSSERANDOT

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Aerodynamic Res. Grouper Leader,
O.N.E.R.A., Paris

PART ONE

The need to reduce takeoff and landing speeds as well as runway lengths required for the operation of modern aircraft has led to studies of new ways to use the main powerplant of the aircraft to lift the machine off the ground.

Tangential blowing, which helps re-attach the boundary layer over a deflected flap, is a means that now enjoys worldwide recognition.

The next step is the object of this study: it consists of circulation control around the wing by means of a blowing jet at the trailing edge, the direction of which can be controlled in flight.

Extremely large lift increases can be obtained by this means, if the energy provided by the powerplant is of the same order of magnitude as that required for the normal operation of the airplane. This is the jet thrust wing, a revolutionary development of long-range significance.

[Adapted from the original by G. Boehler, Dept. of Aero. Eng., Catholic U. of America, Wash., D. C.]

LARGER and larger wing loadings of contemporary airplanes have led to the use of conventional high-lift devices (plain, slotted, split or Fowler flaps) involving a great deal of mechanical complexity and weight.

The idea of increasing flap effectiveness by preventing flow separation, either by suction or blowing, is well known and has been extensively investigated over the past 25 years, in laboratory as well as in flight tests. References 1, 2, 3. The object of this early boundary layer control work was to restore to the flap the theoretical effectiveness predicted by perfect fluid theory in the most economical possible way, by making proper use of the air that could be bled from the airplane's turbo-jet powerplant.

A study of the mechanism of blowing brought to light as early as 1948, Reference 4, the influence of the fun-

Because of its length, this article is being published in three parts. Part I deals with the introduction to circulation control. Part II presents the theoretical development and test results. Part III gives the application of circulation control to aircraft design.

Circulation

damental blowing parameter, the momentum coefficient, and established a distinction between the boundary layer control effect and the circulation control effect.

Figure 1 shows the results of typical tests of tangential blowing over a 20 percent chord flap deflected through 60° . The plot of the lift coefficient as a function of the momentum coefficient clearly illustrates that there are two different actions exerted by the jet.

Reattachment of the boundary layer over the flap, which corresponds to the part AB of the curve, is obtained for small values of C_{μ} . The effect of blowing on the circulation around the airfoil can already be seen in this phase. The intercept of the extrapolated branch A'B of the curve shows that boundary layer control alone corresponds to a lift increase AA'.

Once reattachment of the boundary layer is accomplished, the lift continues to increase with C_{μ} along curve BC. Blowing causes a change only in circulation around the airfoil, the flap chord being artificially extended by the jet downstream of the trailing edge. When C_{μ} increases further, the lift increase is limited only by the leading edge separation, but it requires a much larger expenditure of energy, for equal C_L , than that necessary for preventing separation of the flow over the flap.

For the condition corresponding to point C of Figure 1, for which $\Delta C_{\mu} = 3 C_{\mu r}$, the corresponding lift increase is only $0.55 \Delta C_{Lr}$. It is therefore necessary to emphasize the following point:

Circulation control requires large amounts of power and is practical only if this energy can come from the use of the airplane's jet engine integrated with the wing. From this, there results the concept of the propulsive wing, the lift of which can be changed, at a constant C_{μ} ,

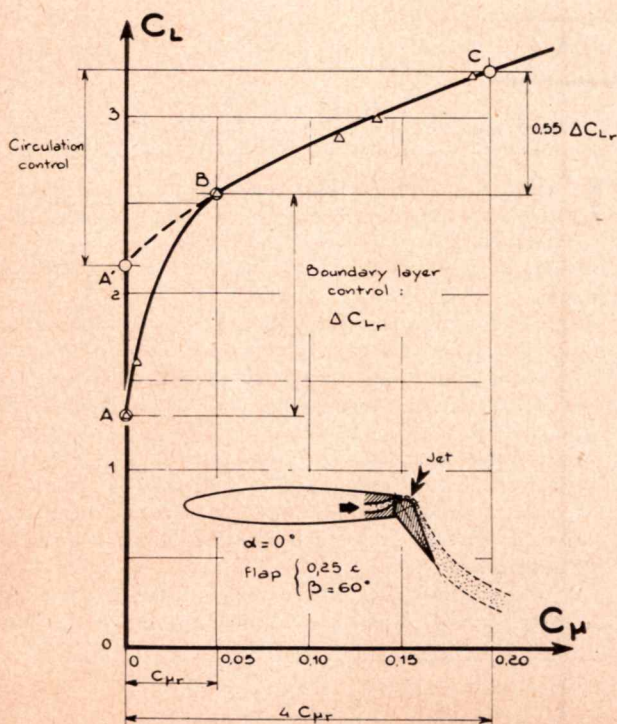


Figure 1—Distinction between boundary-layer control and circulation control.

by changing the orientation of the controlling jet.

At the time of the 1948 tests, no theory of blowing was available to explain the phenomena described in Figure 1 because the blowing jet could not be represented by a source. No source can imply a special jet direction.

At the same time, however, the theoretical problem of boundary layer control by suction had been completely solved by replacing the slot by a sink, and experiments showed that the lift increase, for a given mass flow being sucked, became larger and larger as the slot was moved closer to the trailing edge.

On the other hand, German studies, Reference 1, had shown that a blowing jet, located on the lower surface of the wing, near the trailing edge, could produce appreciable lift increases.

Systematic investigations of blowing at the trailing edge of an airfoil were started by the O.N.E.R.A. in 1953. The results of these studies are presented in this paper. They were carried out under the direction and with the constant assistance of the Director of O.N.E.R.A. Many suggestions originated during meetings of the ad-

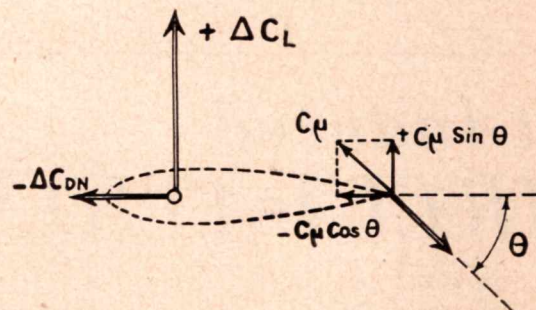


Figure 2a—Jet-induced forces on an airfoil.

visory council of O.N.E.R.A., in which various manufacturers took part, under the chairmanship of Maurice Roy.

The initial objective was to see whether an aft position of the blowing slot resulted in large increases in circulation, over and above any effect on the boundary layer. Experiments showed that it was indeed possible with large amounts of blowing to obtain very large lift coefficients, which were functions of C_{μ} and of the jet direction.

The theoretical method of analysis was first presented in its general form by R. Legendre, Reference 5. By December 1954, the calculation of the effect of the blowing jet could be carried out, resulting in numerical applications by means of the electrolytic tank method, Reference 6.

The aid of a theory which was in good agreement with available experimental results permitted a better understanding of the mechanism of circulation control, predicated upon the existence of a fluid sheet extending from the blowing slot at the trailing edge of the airfoil to infinity downstream.

Theory and experiment were presented in May 1955 at a meeting of the French Association Technique Maritime et Aéronautique in Paris, Reference 7.

A few months later, in October 1955, on the occasion of a lecture given by I. M. Davidson before the British Royal Aeronautical Society, References 8 and 9, it

was reported that similar studies had been conducted simultaneously in Great Britain and in France. Both lectures pointed to the promise of the propulsive wing and to the need for developing special jet engines in order to realize the integration of powerplant and airframe for future aircraft.

Finally, a series of recent communications before the French Académie des Sciences by R. Legendre, L. Malavard and R. Siestrunk give an account of the present status of the theoretical problems.

● ● Jet-Induced Forces on an Airfoil

The proposed use of the trailing edge jet for the propulsion of the airplane underlines the importance of the drag balance of the airplane, which had been completely left aside in previous boundary layer control studies. It is therefore necessary to define carefully the forces acting on a blowing wing moving with a translational velocity, Figure 2a.

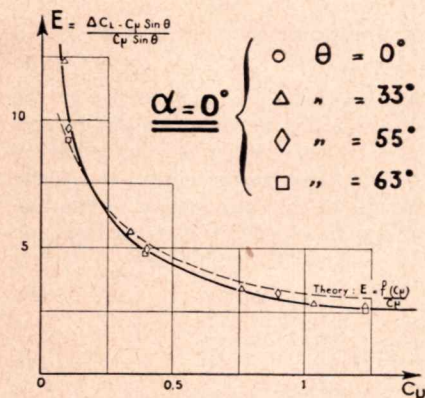


Figure 2b—Variation of lifting effectiveness with jet momentum coefficient.

The trailing edge blowing jet is defined by:

- 1) its impulse $J = q_m V_j$,
or its momentum coefficient $C_\mu = q_j V_j / (\rho/2) U^2 S$
where, q_j = mass flow,
 V_j = jet velocity,
 ρ = free stream mass density, and
 S = wing reference area.
- 2) its orientation θ with respect to the wing chord,
 $\tan \theta = C_\mu \sin \theta / C_\mu \cos \theta$

In this paper, the value of J and the effective orientation of the jet are obtained from tests made by blowing over the model at zero forward velocity, account being made for the velocities induced by the jet on the airfoil.

The blowing jet gives rise to the following forces on the airfoil: a lift increase, ΔC_L ; a drag decrease, ΔC_D ; and a change in pitching moment, ΔC_m .

- 1) The total lift increase consists of two terms:

$$\Delta C_L = \Delta C_{LC} + C_\mu \sin \theta.$$

ΔC_{LC} represents the lift increase due to circulation induced by the jet flap. $C_\mu \sin \theta$ is the vertical component of the reaction of the blowing jet. The lifting effectiveness of the blowing is defined as the ratio of the lift increase due to blowing to the vertical component of the jet reaction:

$$E = \Delta C_{LC} / C_\mu \sin \theta = (\Delta C_L - C_\mu \sin \theta) / C_\mu \sin \theta = (\Delta C_L / C_\mu \sin \theta) - 1$$

The lifting effectiveness based on experimental results is plotted against C_μ in Figure 2b.

- 2) The change in total drag is:

$$\Delta C_D = \Delta C_{DP} + \Delta C_{Di} - C_\mu \cos \theta.$$

ΔC_{DP} is the change in profile drag due to the jet.

ΔC_{Di} is the increase in effective induced drag resulting from ΔC_{Le} .

$C_\mu \cos \theta$ is the horizontal component of the jet reaction. ΔC_L is plotted against ΔC_D in Figure 2c using the same series of tests as in Figure 2b.

It can be shown (Reference 8) that in the idealized case where there is no parasite loss of momentum (on the airfoil or by jet diffusion), the totality of the jet impulse is recovered in the form of thrust, whatever the value of the orientation of the jet.

Disregarding the induced drag, the change in total drag may be written as:

$$\Delta C_D = \Delta C_{DP} - C_\mu \cos \theta = -C_\mu$$

$$\text{or } \Delta C_{DP} = -C_\mu (1 - \cos \theta)$$

In reality, the ideal thrust is never recovered in totality, and one can define the thrust recovery as $-\Delta C_D / C_\mu$.

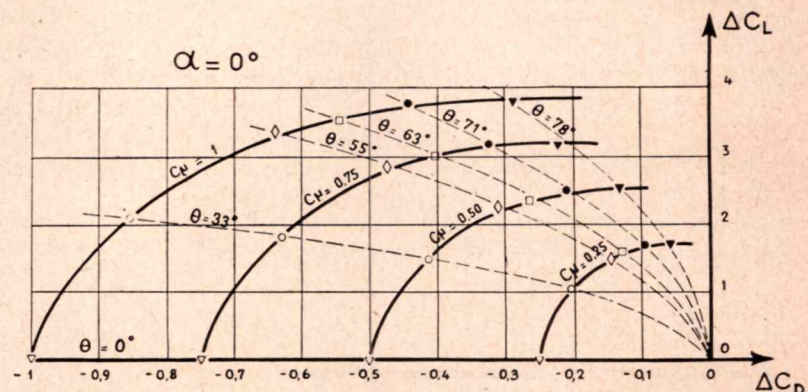


Figure 2c—Variation of lift and drag at zero angle of attack as function of jet orientation and intensity.

For the presentation of wind-tunnel results, the thrust recovery is put in the form $-\Delta C_{DN} / C_\mu$

where, $\Delta C_{DN} = \Delta C_{DB} - \Delta C_{Di}$.

ΔC_{DB} = drag variation measured on the tunnel balance.
 $\Delta C_{Di} = k_i (\Delta C_{Le})^2$ = induced drag calculated from the coefficient k_i of the wing polar without blowing.
 $-\Delta C_{DN} / C_\mu$ is plotted against C_μ in Figure 2d for the same series of tests as in Figures 2b and 2c.

- 3) The blowing jet causes, at a fixed angle of attack, a rearward motion of the center of pressure of the airfoil; its position with respect to the leading edge is given by:

$$x_{cp}/c = \Delta C_m / \Delta C_L,$$

ΔC_m being the change in pitching moment with respect to the leading edge.

Finally, the study of blowing with variable angle of attack indicates an increase of the static stability margin, which is defined by the slope of the (C_L, C_m) curves for a given c.g. location on the wing.

● ● Theory of Blowing Using Linear Approximation

The theoretical analysis presented here is that of the two-dimensional steady motion of a perfect irrotational incompressible flow around an airfoil with trailing edge blowing. When a jet is discharged at the trailing edge of the airfoil, it acts as a flap along an extension of the airfoil, Figure 3a. One assumes that the thickness of

Circulation

the jet remains small far downstream from the airfoil and can be represented by a line of discontinuity of the velocities in the direction of the free stream velocity. The shape of this line is not known beforehand, but it can be determined by requiring that the main forces within the jet be in equilibrium with the external pressures.

The classical assumptions of the linear approximation must be made: thin airfoil, with small camber, at a small angle of attack. It is also assumed that the angle of the jet with the direction Ox of the free stream velocity is small.

Let U be the free-stream velocity parallel to Ox , ρ the free-stream density, c the chord of the airfoil and $y = h(x)$ the equation of the airfoil. Let V_j be the initial jet velocity and, in general, U_j its average velocity in a normal cross-section of the jet; q_j the mass of blown air; and ρ_j the corresponding density. The unknown shape of the jet is defined by $y = j(x)$. The velocity potential of the flow $\Phi(x, y)$ can be written as follows:

$$\Phi(x, y) = Ux + \phi(x, y) \quad (1)$$

where $\phi(x, y)$ represents the potential of the perturbation flow set up by the airfoil and by the trailing edge jet which extends behind it. In keeping with the previous assumptions, the slopes h'_x and j'_x are small. The components $u = \phi'_x$ and $v = \phi'_y$ of the perturbation ve-

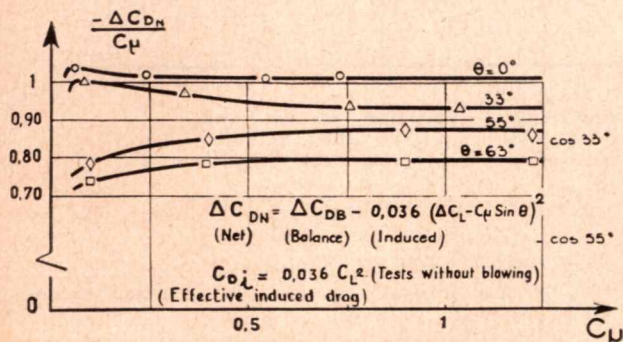


Figure 2d—Variation of thrust recovery with momentum coefficient.

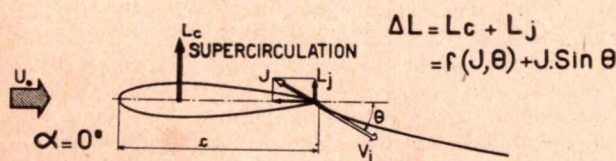


Figure 3a—Airfoil with trailing-edge jet.

locity are also small. In order to determine $\phi(x, y)$, one must express the fact that the stream velocity is tangent to the airfoil and to the jet. Disregarding second-order terms and writing the corresponding conditions on the axis Ox (Figure 3b), that is, on the projections $(-c/2, +c/2)$ of the airfoil and $(+c/2, +\infty)$ of the jet, one has:

$$\text{on } (-c/2, +c/2), v = \phi'_y = U h'_x \quad (2)$$

$$\text{on } (+c/2, +\infty), v = \phi'_y = U j'_x \quad (3)$$

The perturbation potential ϕ and the component u of

the velocity are odd functions of y ; they are discontinuous across the segment $(-c/2, +\infty)$ of the axis Ox and take opposite values for points of same abscissa located opposite to each other on each side of the segment. One need therefore calculate $\phi(x, y)$ only in a half-plane xOy , on the side $y > 0$, for example.

The equilibrium of a fluid element inside the jet requires that the pressure difference δp between the lower and the upper jet boundary, spaced δn from each other, be related to the local jet velocity U_j and the radius of curvature R by the equation:

$$\delta p = -\rho_j U_j^2 \delta n / R \quad (4)$$

or, introducing the mass flow q_j of the jet,

$$\delta p = -q_j U_j / R \quad (5)$$

The pressure difference δp is also applied to the outside flow at the boundary of the jet and can be calculated from Bernoulli's equation as,

$$\delta p = -2\rho U u \quad (6)$$

$\pm u$ represents here the horizontal component of the perturbation velocities along the segment $(+c/2, +\infty)$, respectively, on the sides $y > 0, y < 0$. A comparison between Equations (5) and (6) shows (noticing that $1/R$ is equal in first approximation to j''_x) that

$$u = q_j U_j j''_x / 2\rho U \quad (7)$$

When the jet velocity is large in comparison with the free-stream velocity U , one can assume that the average velocity U_j along the axis of the jet, at any point on the axis, is approximately equal to the initial jet velocity V_j . This hypothesis allows the introduction of the momentum coefficient $C_\mu = 2q_j V_j / \rho U^2 c$ and, using Equation (3), one can write Equation (7) in the form:

$$\phi'_x = c C_\mu \phi''_{xy} / 4 \quad (8)$$

or, after integration,

$$\phi = c C_\mu \phi'_y / 4 + \bar{\phi} \quad (9)$$

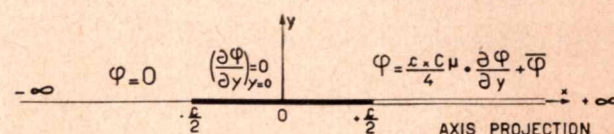


Figure 3b—Boundary conditions for the mathematical problem of trailing-edge blowing.

where the integration constant $\bar{\phi}$ is not known beforehand, but can be determined in terms of the inclination θ of the jet; one has:

$$\bar{\phi} - \phi_{TE} = c C_\mu U \theta / 4, \quad (10)$$

where ϕ_{TE} is the value of ϕ at the trailing edge ($x = +c/2$ on the side: $y > 0$)

In summary, the problem is to find a harmonic func-

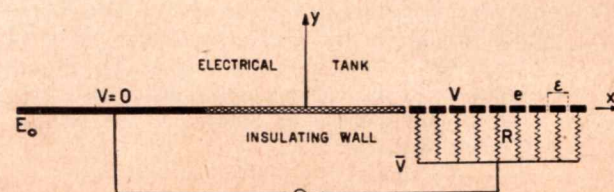


Figure 3c—Tank for two-dimensional airfoil with jet.

tion $\phi(x, y)$ in a half-plane xOy , $y > 0$, with the following boundary conditions on the axis:

- 1) ϕ is zero on the segment $(-\infty, -c/2)$.
- 2) ϕ'_y is known and given by Equation (3) on the segment $(-c/2, +c/2)$.
- 3) On the segment $(+c/2, +\infty)$, one must satisfy at each point Equation (9) which gives a linear relationship between ϕ and its derivative ϕ'_y .
- 4) At the trailing edge, $x = +c/2$, Equation (10) must be satisfied.

The numerical solution of this problem was obtained in two different manners:

- 1) by a purely analytical method, by making a conformal mapping which transforms the interval $(-c/2, +\infty)$ into a circle and expressing the distribution of ϕ on the circle by means of a trigonometric series.
- 2) by the electrolytic tank method.

• • Electrolytic Tank Method

A general introduction to the electrolytic tank method can be found in Reference 10. Its application to the blowing jet is discussed in Reference 11. The results found with this method were later compared with those of the analytical method and found to agree well. The following discussion is limited to the most important practical case, that of a rectilinear airfoil at zero angle of attack ($h'_x = 0$) with a trailing edge blowing jet inclined at angle θ with respect to axis Ox .

In the type of electrical analogy used, the perturbation potential $\phi(x, y)$ is represented by the electrical potential $V(x, y)$ of a plane electrolytic tank of large size, which represents the half-plane xOy , Figure 3c. One of the sides of the tank is taken as an analogical image of the axis Ox ; the part of this side that corresponds to the interval $(-\infty, -c/2)$ is covered with an electrode E_0 which is raised to a potential $V = 0$ in order to satisfy condition (1) above. The interval $(-c/2, +c/2)$ is represented by an insulating wall, since the normal derivative V'_y , which is proportional to the electrical current density along Ox , must be zero in order to satisfy condition (2): $\phi'_y = h'_x = 0$. In the interval $(+c/2, +\infty)$ which represents the jet, are disposed a large number of small electrodes e connected as shown in Figure 3c through resistors R to an alternating current source. Let σ be the conductivity of the electrolyte in the tank, h the height of the electrolyte and ε the width along Ox of an electrode e . The current i which enters the tank through this electrode is:

$$i = -\sigma V'_y h \varepsilon \quad (11)$$

The intensity i can be evaluated from the loss in potential $\bar{V} - V$ through the resistor R , and one has the relationship,

$$\bar{V} - V = -\sigma R h \varepsilon V'_y \quad (12)$$

Choosing the following value for the resistor,

$$R = (C_\mu/4) (c/\sigma h \varepsilon), \quad (13)$$

one can write,

$$V = c C_\mu V'_y/4 + \bar{V}. \quad (14)$$

This relationship is formally similar to Equation (9), where the electrical potential $\bar{V}$ represents the constant $\bar{\phi}$.

For each value of the momentum coefficient C_μ , one adjusts the resistors to the value R given by Equation

(13) and one measures the electrical potentials V along the axis Ox .

• • Circulation and Lift

The value of the circulation Γ around the airfoil is equal to $2\phi_{TE}$. In the electrolytic tank analogy, it is given by the measure of the electrical potential V_{TE} at the point $x = +c/2$, at the end of the insulating wall. The value of the circulation which is thus measured corresponds to the lift increase due to blowing.

The increase in lift coefficient $\Delta_1 C_L$ corresponding to this circulation increase, is given by:

$$\Delta_1 C_L = 2\Gamma_1/Uc = 4V_{TE}/Uc, \quad (15)$$

or, using Equation (10):

$$\Delta_1 C_L = C_\mu \theta V_{TE}/(\bar{V} - V_{TE}). \quad (16)$$

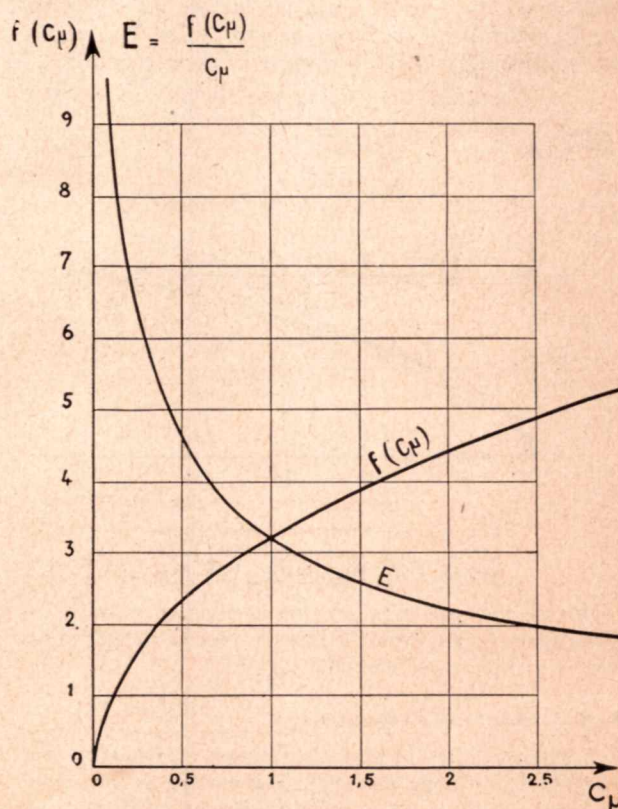


Figure 4—Theoretical variation of the blowing function and the lifting effectiveness with the momentum coefficient.

The ratio $E = V_{TE}/(\bar{V} - V_{TE})$ is the lifting effectiveness. Its variation with C_μ is shown in Figure 4. Also plotted in this figure is the function $f(C_\mu = C_\mu V_{TE}/(\bar{V} - V_{TE}))$, which corresponds to the lift increase $\Delta_1 C_L$ for a jet angle of one radian.

The application of the principle of conservation of momentum and the calculation, according to Joukowski's rule, of the effect of the outside flow on the airfoil contour extended by the jet line, which is assumed to be materialized in the region where it has an appreciable curvature, show the existence of a component of thrust equal to the jet impulse ($C_D = -C_\mu$) whatever the direction θ of the blowing jet, together with a vertical component corresponding to the value of the circulation of the free stream $\Gamma = 2\bar{\phi}$ for a system represented by conformal mapping of a circle of infinite radius.

The vertical component gives a lift increase,

Circulation

$$\Delta C_L = 2\Gamma/Uc = 4\bar{V}/Uc = C_{\mu}\theta + 4V_{TE}/Uc \quad (17)$$

or,

$$\Delta C_L = [f(C_{\mu}) + C_{\mu}]\theta \quad (18)$$

One can thus verify that it is equivalent to apply Joukowski's rule to the fictitious profile including in addition to the basic airfoil the jet assumed to be materialized, or to apply it to the airfoil alone and add the vertical component $C_{\mu}\theta$ of the momentum of the jet.

Strictly speaking, this last component is equal to $C_{\mu} \sin \theta$. Therefore, one probably can extend the previous theory to a wider range of inclinations θ by replacing θ by $\sin \theta$ in Equation (18). By this means, the total increase in lift coefficient is given by:

$$\Delta C_L = [f(C_{\mu}) + C_{\mu}] \sin \theta. \quad (19)$$

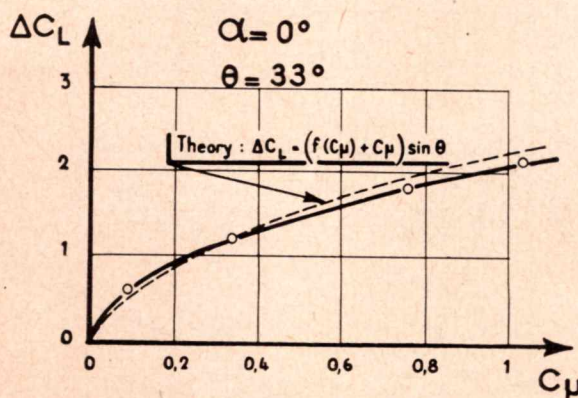


Figure 5a—Comparison of theoretical and experimental variations of lift with blowing.

This formula shows a satisfactory agreement with experimental results, even for large values of θ , as can be seen from Figures 5a and 5b.

Center of Pressure

A determination of the distribution of the electrical potential $V(x)$ along the insulating portion of the model (interval $-c/2, +c/2$) permits calculation of the position of the center of pressure. The forces created by the supercirculation Γ give a resultant located at an abscissa x_1 from the leading edge, such that,

$$\begin{aligned} x_1/c &= 1 - \left[\int_0^1 \phi d(x/c) \right] / \phi_{TE} \\ &= 1 - \left[\int_0^1 V d(x/c) \right] / V_{TE} \end{aligned} \quad (20)$$

If one in addition includes the effect of the jet reaction (its moment about the leading edge of the airfoil is $cC_{\mu} \sin \theta$), the abscissa x_{CP} of the center of pressure is given finally by

$$\frac{x_{cp}}{c} = C_{\mu} + \frac{f(C_{\mu}) (x_1/c)}{f(C_{\mu}) + C_{\mu}} \quad (21)$$

This equation shows that the location of the center of

pressure is independent of the orientation of the jet. Experimental results agree with this theoretical prediction as shown in Figure 5b.

Shape of the Jet

By determining the variation of potential $V(x)$ on the segment $(+c/2, +\infty)$, one can define the shape of the jet. One has:

$$j'_x = \phi'_y/U = - \left[\frac{V-V}{\bar{V}-V_{TE}} \right] \theta \quad (22)$$

The equation $y = j(x)$ may be determined from this relationship by integration.

The theoretical shape of the jet calculated in this manner is in good agreement with the results of pressure surveys made aft of the airfoil to determine the positions of the axis of the jet at different locations downstream of the wing.

Extension of the Theory

The electrolytic tank method can be used to treat the general case of a thin airfoil of any shape. It was pos-

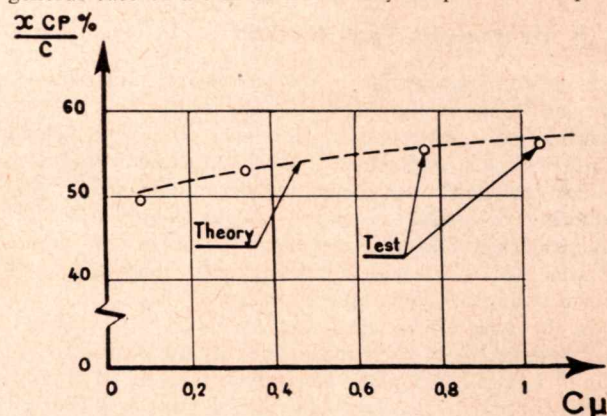


Figure 5b—Comparison of theoretical and experimental variations of center of pressure with blowing.

sible to calculate the lift increase of an airfoil at an angle of attack with a jet extending the airfoil (for a jet deflection θ equal to the angle of attack α) and the combined effect of a jet blowing over a deflected flap.

The method described above does not permit an easy determination of the streamlines. However, one can draw the streamlines directly by using another method, which is based on a different principle.

Assuming that the shape of the jet is only slightly influenced by the thickness of the airfoil, it is possible to take the shape defined by the linear approximation of Equation (22) and materialize it by extension of the airfoil in the form of a curved wall. To draw the streamlines, all that is necessary is to place a conductor model reproducing the airfoil and the jet contour in the middle of a two-dimensional tank with two parallel electrodes, as shown in Figure 6. The classical determination of the electrical equipotentials provides the streamlines of the flow. Such a determination is shown in Figure 7 for a NACA 0018 airfoil, with $\theta = 31.4^\circ$ and $C_{\mu} = 1$. The theoretical field can be compared with figure 8, which represents the visualization of a similar flow in a water tank.

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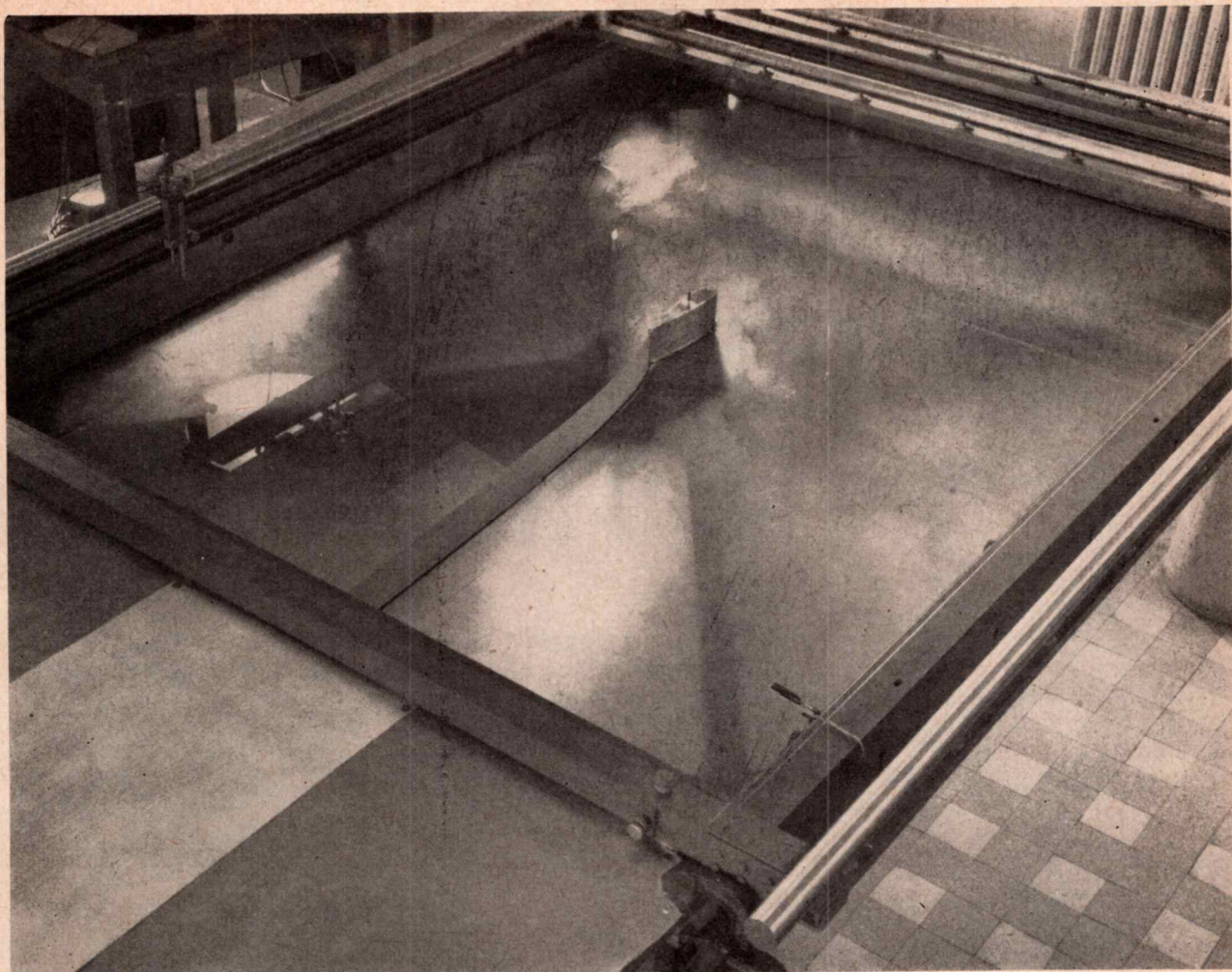


Figure 6—Tank for determining the streamlines.

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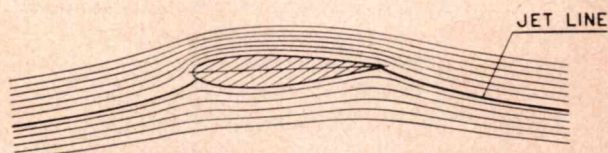


Figure 7—Streamlines of two-dimensional airfoil with trailing-edge jet.

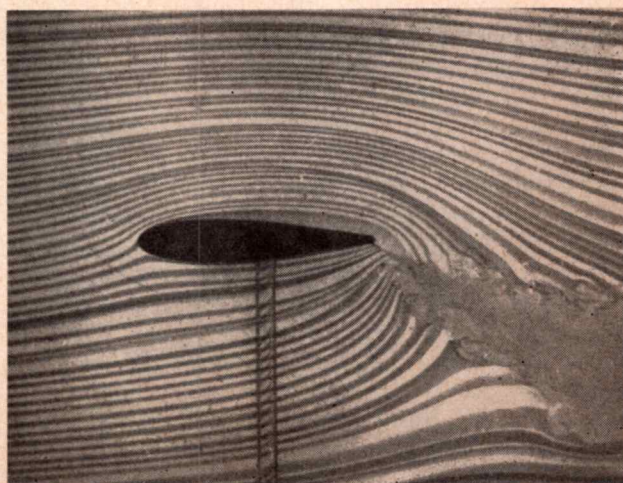


Figure 8—Visualization of the streamlines of an airfoil with jet in the water tank.

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Designing for the Automatic CONTROL OF

Jet engines must have built-in protection against excessive temperature, excessive speed and fuel flow, and at the same time give high performance. One practical method is furnished by hydraulic-mechanical circuitry.

THE CONTROL of a jet engine is often taken for granted, since it is thought to consist essentially of a fuel spigot that can be turned on and off to accelerate and decelerate the engine, and a pair of flyweights hooked in somewhere to control the engine speed.

Ten years ago many turbojet controls did not much exceed this degree of elegance, except that barometric compensation for altitude generally was used.

Nowadays, however, the necessity for rapid response of the engine to throttle movement, the "snappiness" of the acceleration of modern engines, and their sensitivity to changes in operating environment, as well as the tremendous range of altitudes and flight speeds to which they are subjected, have created a need for precise and accurate control of the fuel spigot, which will hereafter be dignified by the term "valve."

The design and building of jet engine controls has become a refined art. The objective is to get optimum performance from the engine, while protecting it from damage due to excessive fuel admission, overspeed or overtemperature. This article is confined principally to a description of a mechanism to take care of these matters during automatic or "throttle burst" acceleration.

A statement of the problem is given by an abbreviated and idealized analysis of the operation of a jet engine (for example, all components are assumed to be perfectly efficient), followed by a description of the mechanical computing means—which in some form or other are mandatory for modern controls—that were devised to execute the prescribed functions. No attempt is made to analyze the transient performance of the control components, although before reduction to

SYMBOLS

A	= port area of a metering valve
A_B	= effective cross-section area of a sensing bellows
C	= a constant
C_p	= specific heat of air at constant pressure
F, f	= functional relationships
H	= heating value of fuel
h	= hydraulic oil pressure
K, k	= constants
l, m, n	= lever lengths
N	= rpm
P	= total pressure of a gas
p	= pressure (fuel or air)
T	= total temperature of a gas
W_A	= rate of air flow
W_F	= rate of fuel flow
x, y, z	= output displacement of mechanical computers

Greek letters:

γ	= ratio of specific heats of air (1.4)
δ	= air pressure in units of one atmosphere
Θ	= air temperature above absolute zero in units of 518.4°F
Φ	= functional relationship

Subscripts:

1	= compressor inlet
2	= compressor discharge
3	= turbine inlet
4	= turbine discharge

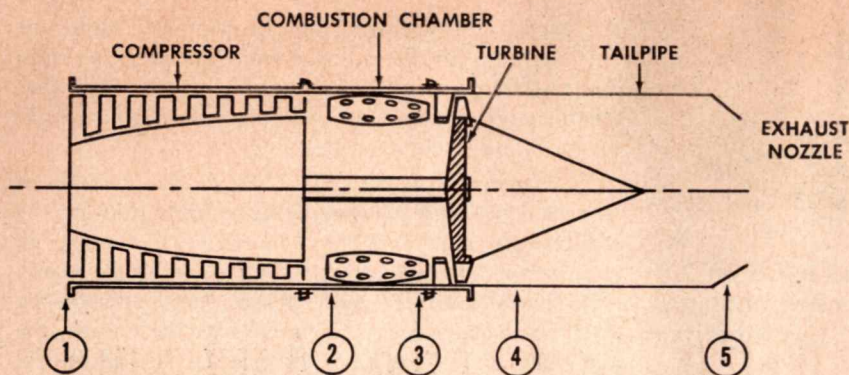


Figure 1—Longitudinal cross-section of a turbojet engine.

TURBOJET ENGINES

hardware, a transient analysis of the mechanism is essential if problems such as instability are to be avoided.

● ● Hydraulic-Mechanical Control

There are many ways in which the control computations may be carried out by practical mechanisms—by electrical or hydraulic circuitry, for example. The control described is of the hydraulic mechanical type, and even in this sub-species, several ways are available for the performance of the computations—logarithmic means, linkages and cam combinations, to name a few. The particular mechanisms described must therefore be considered only as examples and not as unique solutions.

Figure 1 shows diagrammatically a longitudinal cross-section of a turbojet engine. Air is drawn into the axial-flow compressor at station (1), where the total (or stagnation) pressure of the air is P_1 and the total temperature T_1 . The air is discharged at station (2) at a higher pressure and temperature P_2 and T_2 . The airstream then enters the combustion chamber, where fuel is injected and burned, raising the temperature to T_3 . The hot gas is then expanded through the turbine down to the tailpipe pressure and temperature, P_4 and T_4 . During its passage through the turbine, work is extracted from the gas, and this work is used to drive the compressor. At the turbine exit, station (4), the pressure of the gas is still above that of the ambient atmosphere, and this pressure is used to force the exhaust gas through the nozzle at station (5) with high velocity.

The turbine behaves much like a nozzle with respect to the flow of gas through it; and as in the case of a

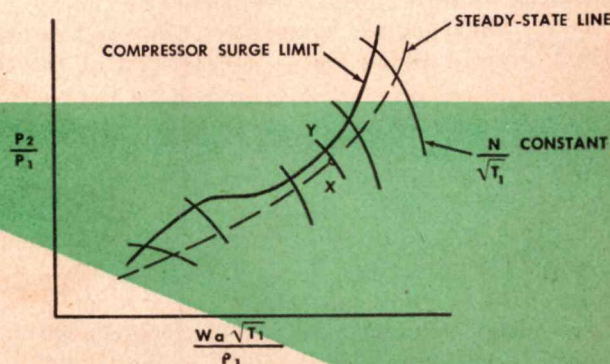


Figure 2 — Representation of compressor characteristics.

nozzle, the flow may be related to the upstream and downstream pressures and temperatures by the following expression:

$$(W_A \sqrt{T_3/P_3}) = f(P_3/P_4)$$

Over most of the operating range of the turbine the gas flow is super-critical, or "choking," and the functional expression on the right becomes a constant, which we denote by K . Using this, and adding some simple algebra, we get

$$(W_A \sqrt{T_3/P_3}) = (W_A \sqrt{T_1/P_1}) [(P_1/P_3) \sqrt{T_3/T_1}] = K$$

Since the total gas pressure at station (3) in Figure 1 is substantially the same as at station (2), this equation may be written as

$$(W_A \sqrt{T_3/P_2}) = (W_A \sqrt{T_1/P_1}) (P_1/P_2) \sqrt{T_3/T_1} = K \quad (1)$$

We now develop another relationship, starting with the following simple expression:

$$(T_3/T_1) = (T_2/T_1) + (T_3 - T_2)/T_1 \quad (2)$$

Since the compression of air between stations (1) and (2) is adiabatic,

$$(T_2/T_1) = [P_2/P_1]^{\frac{\gamma-1}{\gamma}} \quad (3)$$

Turbojet

Also, since the temperature rise ($T_3 - T_2$) is due to the combustion of fuel between stations (1) and (2),

$$[(T_3 - T_2)/T_1] = (W_F/W_A) (H/C_p) (1/T_1) \quad (4)$$

where H is the heating value of the fuel in btu per lb, and C_p is the specific heat of air at constant pressure. Substituting equations (3) and (4) into equation (2), we get

$$(T_3/T_1) = [P_2/P_1] + (W_F/W_A) (H/C_p) (1/T_1) \quad (5)$$

We can now eliminate (T_3/T_1) between equations (1) and (5). From equation (1),

$$(T_3/T_1) = [K(P_2/P_1) (P_1/W_A \sqrt{T_1})]^2;$$

and equating this expression to equation (5), we get:

$$\begin{aligned} [K(P_2/P_1) (P_1/W_A \sqrt{T_1})]^2 \\ = [P_2/P_1] + (W_F/W_A) (H/C_p) (1/T_1) \\ = [P_2/P_1] + (W_F/P_1 \sqrt{T_1}) (P_1/W_A \sqrt{T_1}) (H/C_p) \end{aligned} \quad (6)$$

In equation (6), K , H and C_p are constants, and it is seen from the equation that if (P_2/P_1) and ($W_A \sqrt{T_1}/P_1$) are given, it can be solved to give a unique value of $W_F/P_1 \sqrt{T_1}$. The quantity (P_2/P_1) is the compressor pressure ratio, and the quantities $W_A \sqrt{T_1}/P_1$ and $W_F/P_1 \sqrt{T_1}$ are called "corrected air flow" and "corrected fuel flow," respectively.

The conclusion contained in equation (6) is quite important for understanding the principles of the control to be described below.

In place of the symbols P and T used for pressure and temperature respectively, the symbols δ and θ are frequently used. δ denotes the pressure measured in units of one atmosphere (14.69 psia), and θ denotes the temperature above absolute zero measured in units of 518.4°F. When these symbols are used, the values of inlet pressure and temperature become unity for sea level standard conditions.

Compressor Characteristics

Figure 2 shows how the characteristics of a compressor are usually presented. Values of compressor pressure ratio are plotted as ordinates against corrected air flow as abscissae for constant values of corrected engine rpm, $N/\sqrt{T_1}$. Shown on the curve is a dotted line marked "steady state operating line," and a solid line marked "compressor surge limit." Each point on

the steady state operating line determines a value for the corrected air flow, the compressor pressure ratio and the corrected rpm, and these values are such that the turbojet engine is in steady state running equilibrium at every point on this line.

By virtue of equation (6), there is also a value of corrected fuel flow corresponding to each point on the steady state line. Suppose the engine is running in equilibrium corresponding to some point on the steady state line of Figure 2, such as that point indicated by X . If it is now desired to accelerate the engine, the fuel flow to the engine is increased. The additional fuel burns in the combustion chamber, giving an increased temperature of the gases entering the turbine; this increased temperature results in a volumetric expansion and an increase of combustion chamber pressure.

Thus, if the engine has been running in equilibrium at some constant rpm, as indicated at X , an increase in fuel flow will raise the compressor pressure ratio from the ordinate corresponding to X towards that corresponding to Y , and the increased velocity of the gas now flowing through the turbine will cause the engine to accelerate.

But the fuel flow increases must not be permitted to allow the compressor ratio to rise above the value corresponding to the compressor surge limit, given by the upper curve of Figure 2, or severe damage to the engine may result.

Since, as indicated by equation (6), there is a value of corrected fuel flow corresponding to every point on the compressor map, a suggested means for limiting the compressor ratio to safe values is to place a maximum limit on the corrected fuel flow at each value of corrected air flow.

Fuel Flow Control

A study of the compressor map, Figure 2, discloses that several groups of engine variables may be used to control or limit the maximum engine fuel flow. A few of these are listed below:

$$\begin{aligned} (W_F/P_1 \sqrt{T_1}) &= f(W_A \sqrt{T_1}/P_1); \\ (W_F/P_1 \sqrt{T_1}) &= f(P_2/P_1); \\ (W_F/P_1 \sqrt{T_1}) &= f(N/\sqrt{T_1}). \end{aligned} \quad (7)$$

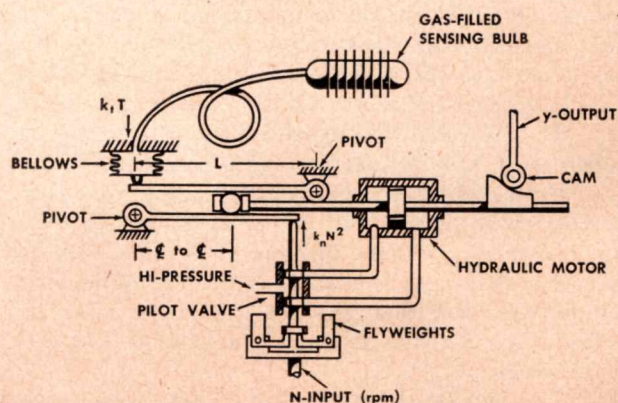


Figure 3—Corrected speed computer.

The choice of the functional relationship to be used in any particular case depends on the ease and accuracy with which the variables may be measured, and the practicality of designing computers to reduce the measured variables to actual mechanisms for controlling the engine fuel flow.

In the particular control discussed here, the last named of the above relationships was selected for reduction to actual hardware.

In this control, the engine rpm, compressor inlet air temperature and compressor inlet air pressure are measured and fed into the control. The control contains hydraulic-mechanical computing mechanisms that solve equation (7), and the fuel flow to the engine is limited to the values permitted by the equation at each set of engine conditions.

Equation (7) is rearranged as:

$$W_F = P_1 \sqrt{T_1} f(N/\sqrt{T_1}) \quad (8)$$

The formula for flow of liquid fuel through a metering orifice in a valve is

$$W_F = CA\sqrt{\Delta p}, \quad (9)$$

where C is a constant, A is the flow area of the valve orifice, and Δp is the pressure drop through the valve.

If now the port area A is made proportional to $P_1 f(N/\sqrt{T_1})$, and the pressure drop Δp is made proportional to T_1 , the control will produce a fuel flow in accord with the following equation:

$$W_F = k P_1 \sqrt{T_1} f(N/\sqrt{T_1}) \quad (10)$$

The control may be designed so that the constant k is equal to unity, in which case equations (8) and (10) are identical, and the problem is solved.

The mechanisms to be described, for the solution of equation (10), consist of:

- a) the corrected-speed computer ($N/\sqrt{T_1}$);
- b) the P_1 multiplier; and
- c) the metering head (Δp) control.

• • Corrected-Speed Computer

The corrected-speed computer is shown schematically in Figure 3. A pair of parallel levers is arranged as shown, the two levers being separated by a pair of rollers which can be translated by the hydraulic ram motor at the right.

The upper lever is loaded by a gas-filled flexible bellows connected to a sensing bulb, which is exposed to the engine inlet air stream. The pressure in the bulb and bellows is thus proportional to the absolute temperature T_1 of the engine inlet air.

The lower lever is loaded as shown by the force from a pair of engine-driven flyweights, and is thus subjected to a force that is proportional to N^2 .

A spool-type pilot valve is attached to the flyweight push rod, and when this valve is displaced from its shut-off position, hydraulic fluid is admitted or extracted from the hydraulic ram cylinder.

Considerations of force and moment equilibrium of the lever and roller (nut-cracker) system under the forces acting on it lead to the equation

$$(N/\sqrt{T_1}) = \sqrt{(k_n/k_t) [x/(L-x)]} \quad (11)$$

The displacement x of the rollers thus gives a measure of the "corrected speed" of the engine. The porting of the pilot valve and ram cylinder is such that any disturbance from equilibrium, either by a change in air temperature or a change in engine speed, will result in a roller and piston movement in a direction that will restore the system equilibrium.

Mounted on the piston rod of the hydraulic cylinder is a cam, profiled in such a way that the rise y of the cam follower is

$$y = F(N/\sqrt{T_1}) \quad (12)$$

The mechanism just described thus solves part of the problem stated by equation (10), namely that of measuring engine inlet air temperature and engine rpm, and producing an output that is a function of the rpm divided by the square root of the temperature. To

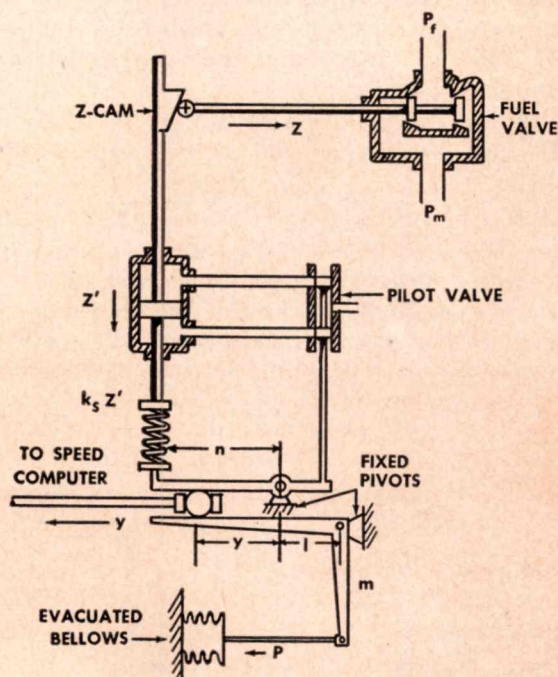


Figure 4— P_1 multiplier.

carry the solution one step further, we take the output y of Figure 3 and multiply it by P_1 .

The P_1 multiplier is shown schematically in Figure 4. It, like the corrected speed computer, is of the nut-cracker type comprising two parallel pivoted levers separated by rollers capable of translatable motion. The configuration is slightly different from the nutcracker of Figure 3 for reasons involving sensitivity and response.

In Figure 4, the output y from the function cam of the corrected speed computer becomes the input to the P_1 multiplier. The lower lever is loaded by the force due to the pressure P_1 acting on evacuated bellows, and the upper lever is loaded by a variable compressed

Turbojet

spring. Attached to the upper lever is a spool-type pilot valve that is ported to a hydraulic ram. Equilibrium of forces and moments on the pair of levers leads to the expression

$$Z' = P_1 (A_B m / k_s) [y / (l - y)], \quad (13)$$

where Z is the displacement of the upper end of the spring.

Since the input y is a function of the corrected speed, equation (13) can be written

$$Z' = P_1 \cdot \phi' (N / \sqrt{T_1}) \quad (14)$$

Equation (14) has completed another step in the computation expressed by equation (10).

In the upper portion of Figure 4 is shown a linear cam that is attached to a fuel-metering valve. The lift of the valve from its seat is Z , which is proportional to Z' . The metering port area of the valve is thus proportional to Z , giving

$$Z = P_1 \cdot \phi (N / \sqrt{T_1})$$

The fuel flow through the metering valve is thus given by

$$W_F = k_F P_1 \phi (N / \sqrt{T_1}) \sqrt{p_F - p_m}, \quad (15)$$

where p_F and p_m are the fuel pressures upstream and downstream, respectively, from the metering valve.

The next step in the mechanical computation of corrected fuel flow as a function of corrected speed is to maintain $(p_F - p_m)$ proportional to the absolute tem-

perature T_1 of the air entering the compressor. When this is done, the similarity of equation (15) to equation (8) is apparent.

• • Metering-Head Control

The mechanism by which $(p_F - p_m)$, on the "metering head" is kept proportional to T_1 during engine acceleration is shown diagrammatically in Figure 5. The particular jet-engine control model that used the mechanisms described here was arranged to use engine lubricating oil as the hydraulic actuating fluid in the computing mechanisms. In Figure 5 the letter h denotes a hydraulic oil pressure, and the letter p denotes a fuel pressure.

Referring now to Figure 5, we see in the center of the diagram a pair of bellows, marked A and B. In the bellows A, a pressure difference $(h_m - h_o)$ is set up between the interior and exterior, and this pressure difference is proportional to the absolute air temperature T_1 . A gas-filled bulb is exposed to the airstream and connected to a bellows E shown at the left of Figure 5. This bellows is attached to one end of a center-pivoted lever, at the other end of which is an evacuated bellows of equal area, whose function is to cancel out the effect of external pressure. The bulb and bellows E being filled with dry gas, the pressure therein is proportional to the absolute temperature of the gas. Attached to the gas-filled bellows is a small oil pressure regulating valve, supplied with oil at a moderately high pressure through a bleed orifice G. The pressure in the line H is thus regulated so that $(h_m - h_o)$ is proportional to the temperature T_1 to which the sensing bulb is exposed.

This pressure difference $(h_m - h_o)$ is sensed by the bellows B. Connected to this bellows through a cross-shaft is an identical bellows A, which senses the pressure difference $(p_F - p_m)$ across the main fuel metering valve. If the pressures $(p_F - p_m)$ and $(h_m - h_o)$ are equal, the system remains in equilibrium. If these pressures are not equal, the equilibrium is disturbed, and a pilot valve D is displaced from its neutral position. Such a displacement will admit or extract oil from the power piston attached to the fuel by-pass valve shown at the right, resulting in an opening or closing of the by-pass valve as a rate proportional to the difference, or "error" between $(h_m - h_o)$ and $(p_F - p_m)$.

The fuel to the engine is supplied from a gear pump shown at the upper right of Figure 5, and the opening or closing of the by-pass valve in the manner described above will result in by-passing more or less of the pump output away from the metering valve. Such a change in the fuel flow admitted to the metering valve results in a change in the pressure drop $(p_F - p_m)$, which is thus quickly restored to its desired equality with $(h_m - h_o)$.

The metering pressure drop $(p_F - p_m)$ being kept proportional to T_1 in the way just related, means that the control will produce a fuel flow as described by equation (15), but in which we can substitute T_1 (multiplied by a constant) in place of $(p_F - p_m)$. By a

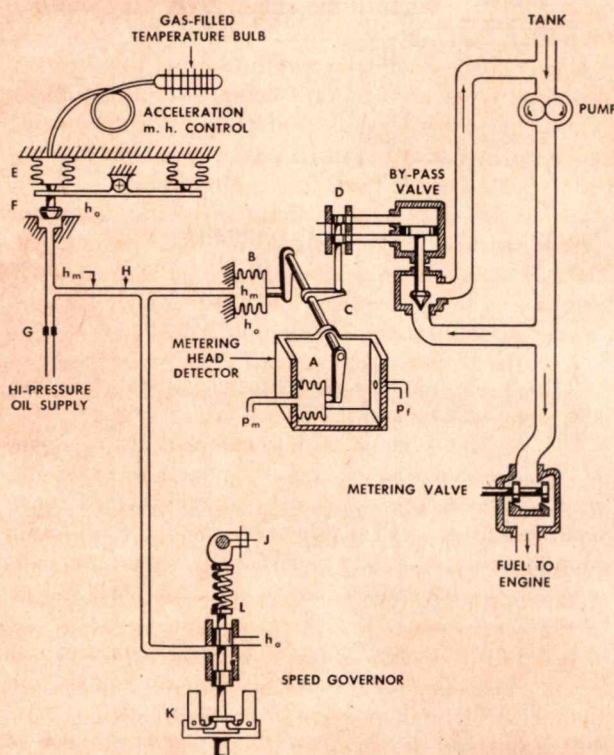


Figure 5—Metering-head control.

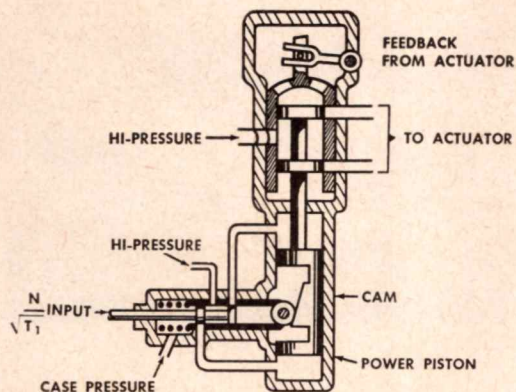


Figure 6 — Amplifier for varying engine geometry as function of corrected speed.

proper choice of dimensions in the control, it is seen that equation (15) reduces to

$$(W_F/p_1\sqrt{T_1}) = f(N\sqrt{T_1}),$$

which is identical with equation (7). The mechanisms described are thus capable of limiting the maximum engine fuel flow to the values theoretically required by thermodynamic considerations, and it is noteworthy that these mechanisms produce the correct relationships regardless of engine operating conditions (altitude and ambient temperature). The control will automatically keep the engine within safe transient operating limits without attention from the pilot, and this is frequently quite an important consideration.

● ● Steady-State Speed Governing

Speed governing in steady state running is achieved in a simple manner. Shown at the bottom of Figure 5 is a pair of flyweights K, which are geared to the engine shaft. These flyweights press upward on a spool valve with a force proportional to the square of the engine speed. The spool valve is pressed downward by a spring whose force is determined by a manually-set cam J. The angular position of the cam determines the rpm at which the engine speed is to be regulated. For any setting of the cam and spring, at low speeds the spring force overcomes the flyweight force, and the spool valve is held in the down position. As the engine speed increases under automatic acceleration at maximum permissible fuel flow rate, the force of the flyweights increases and eventually it overcomes the spring force, allowing the spool valve to rise and crack open a port in the valve sleeve, shown at L. When this port opens, fluid is spilled out of the h_m line, resulting in a lowering of the pressure difference ($h_m - h_o$), and a consequent lowering of the fuel metering head ($p_F - p_m$). This reduction in metering head produces a reduction in engine fuel flow, with the result that acceleration of the engine soon ceases, and the speed of rotation settles out at a value equal to that at which the flyweight force is just equal to the spring force of the manually set "speeder" spring.

This type of speed governor gives proportional or "droop" control of speed, and the engine speed may be

expected to vary as operating conditions change. In this control, however, because of the action of the corrected speed computer and the p_1 multiplier on the fuel valve, the effect of varying ambient conditions is largely compensated for, and the speed governing becomes practically isochronous, while retaining the advantages of stability and freedom from hunting that pertain to the proportional type of control.

In Figure 2, the line representing the compressor surge limit is everywhere higher than the steady state line. In modern high compression ratio engines, different parts of the compressor blading may go into stall at compression ratios less than those required to stall the whole machine, and often the limit of stable operation is below the steady state operating line in some portions of the map. In such cases it would be impossible to accelerate the engine to full speed without encountering compressor surge. To avoid this difficulty, modern engines frequently use a two-spool rotor, consisting of two co-axial but independent engines, or alternatively, variable pitch compressor blading is resorted to. In the latter case, the blade pitch angle should be a function of corrected speed.

● ● Hydraulic Amplifier

The control described here contains a corrected speed computer, and a signal of corrected speed is available to vary the compressor blade angle of the engine. The mechanism by which this is done is depicted in Figure 6. The x output from Figure 3 is fed into a hydraulic amplifier fitted with a cam that determines the relationship of blade angle to corrected speed.

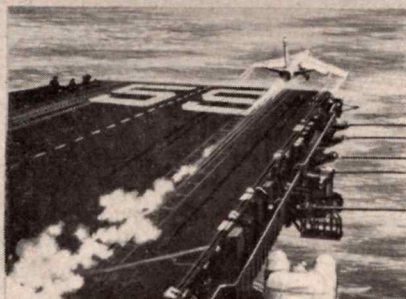
As seen in Figure 6, there are two stages of amplification, the final output being a hydraulic power supply to a remote actuator, not shown in the diagram, with a mechanical feedback to the amplifier as shown in the diagram.

While in the particular application of this control, the amplifier is used to vary compressor blade angle, it could of course serve to control any variable engine geometry as a function of corrected speed, such as exhaust nozzle area or inlet duct configuration.

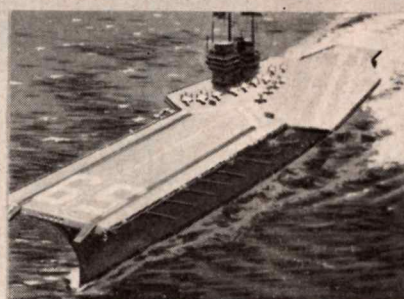
No mention has been made of a specific means for controlling turbine temperature by direct measurement. The gas temperature at the inlet to the turbine is determined by the compressor inlet temperature, the compressor pressure ratio, the engine speed and the fuel flow to the engine. The necessity for providing turbine temperature measuring means, with equipment for protecting the engine against damage from excessive temperature, is dependent on the particular engine involved. Many engines are in use today with no provision in the control for use of a turbine temperature signal, and satisfactory operation is obtained when the fuel flow is controlled as a function of the variables, air pressure, air inlet temperature and rpm. In the control described in this article, a device was included for reduction of fuel flow to the engine in case excess turbine temperature is encountered, but the primary control function rests in the hydraulic-mechanical mechanisms described in the article. ♦ ♦



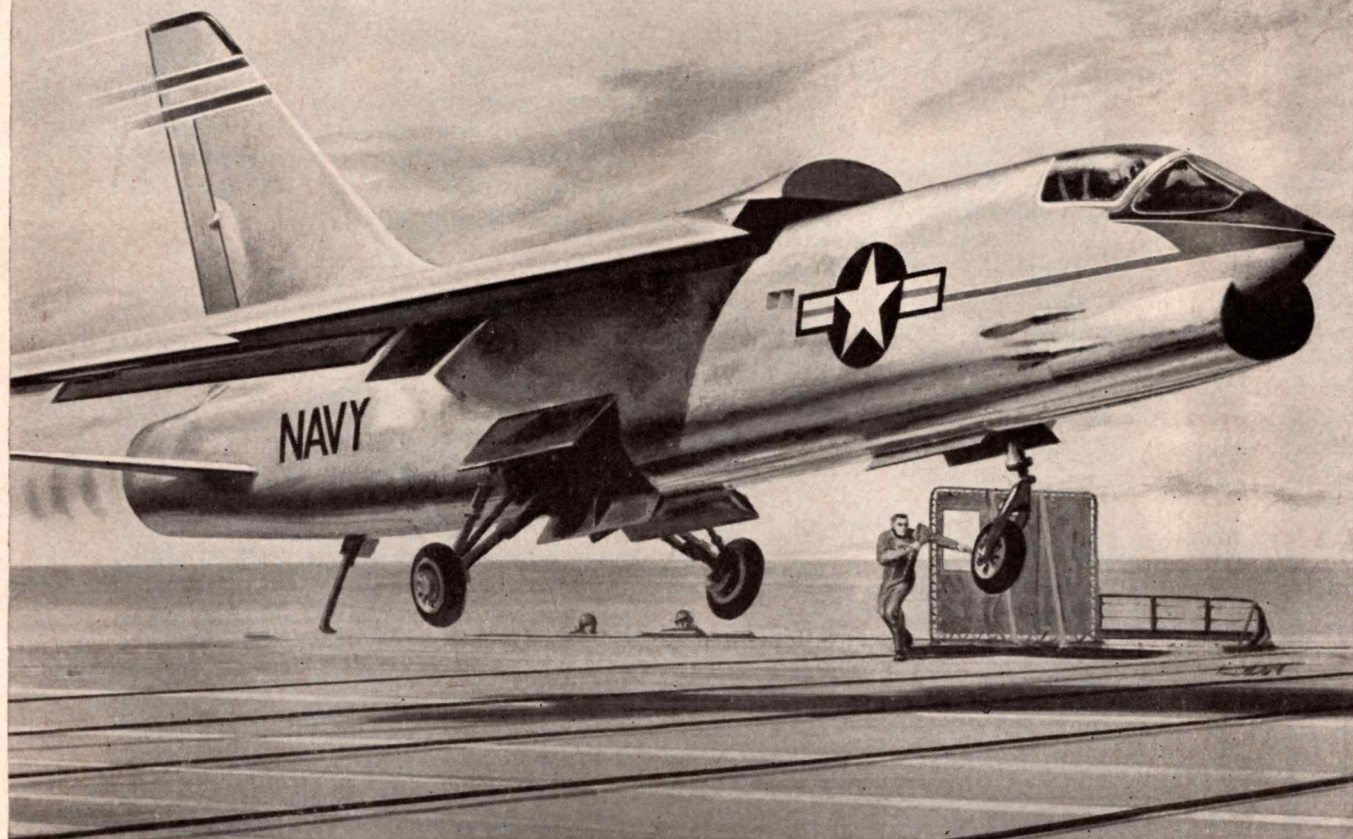
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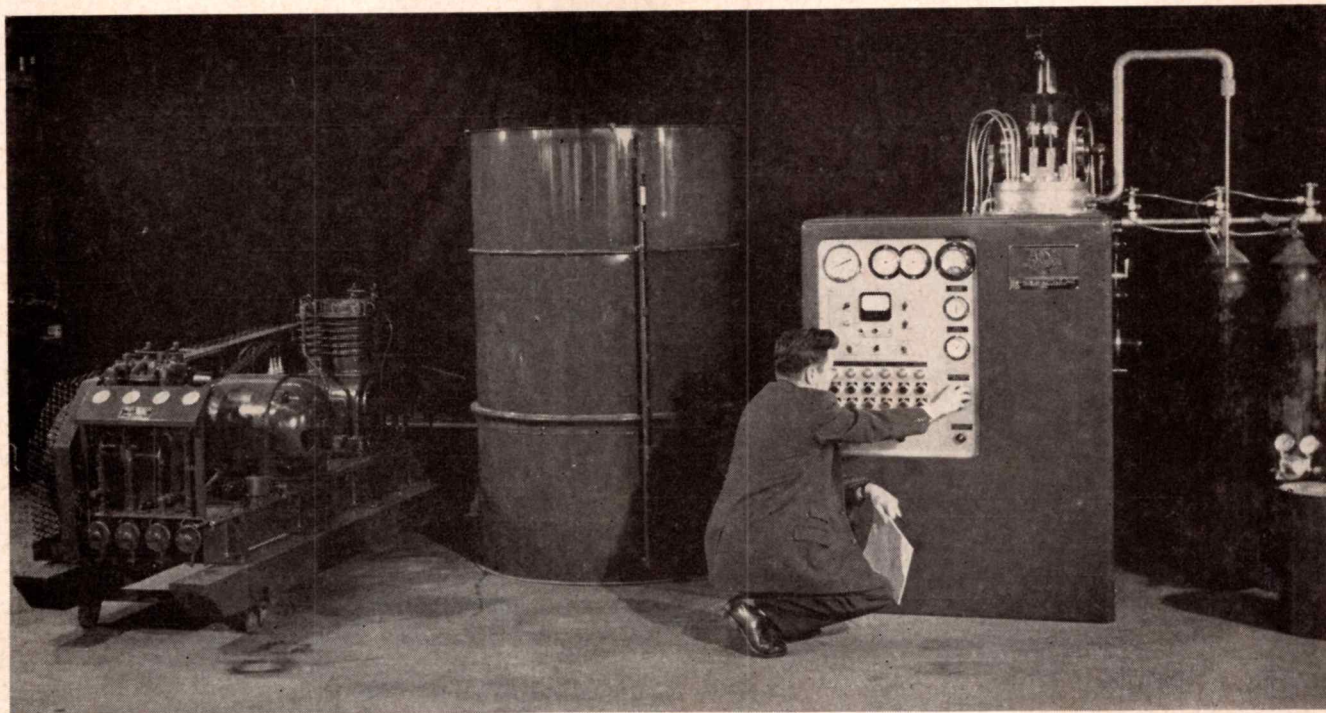
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Figure 1—Complete ADL Collins Helium Cryostat unit with liquefier cabinet, compressor, gas holder and helium purifier.



Helium-refrigerated generating systems show promise for

LIQUID HYDROGEN

As a Rocket Propellant

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L IQUID HYDROGEN, as a rocket motor fuel, has been in use on an experimental basis for several years. Its potential widespread use may be hindered by the unfamiliarity of many rocket engineers with the recent developments in liquefaction and storage of hydrogen by simple means. Of particular interest is a low pressure helium refrigerated system developed during the past nine years. It will contribute to making the experimental and field use of liquid hydrogen much more practical than previously possible. This system provides refrigeration for liquefaction and prevents evaporation loss during storage and during shipment.

Figure 1 gives some selected information on hydrogen as applied to liquefaction and to its possible use

as a rocket fuel. Similar information is tabulated for oxygen for comparison. Some of the possible propellant combinations of liquid hydrogen are shown in Figure 2. Many thousand gallons of hydrogen have been liquefied during the last few years. But because of the unusually wide explosion limits of hydrogen-air mixtures (4.1 percent hydrogen to 74.2 percent hydrogen), hydrogen must be handled with care. There have been explosions in hydrogen compression and in the handling of high pressure hydrogen cylinders; some explosions have resulted from rapid compression of hydrogen-oxygen mixtures following carelessness in allowing air to enter a system and then admitting hydrogen from a high pressure cylinder (approximately 2000 psi) too rapidly. Mechanical failure of high pressure hydrogen equipment frequently results in an explosion or severe fire due to ignition of the hydrogen-air mixture adjacent to the rupturing metal.

Studies of minimum explosion temperatures of hydrogen-oxygen mixtures reveal that, from experi-

Figure 2 — Flow diagram of helium refrigeration system.

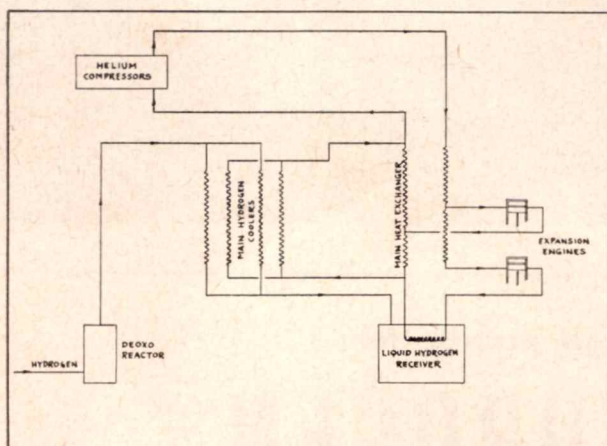
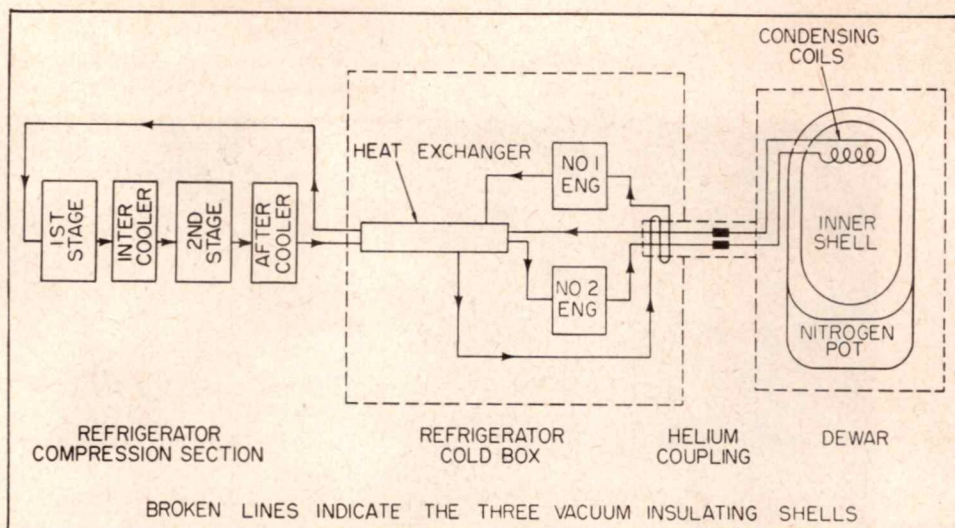


Figure 3 — Cycle diagram for helium-refrigerated low-pressure hydrogen liquefier.

ments with compressing various mixtures of hydrogen and oxygen adiabatically in a piston-cylinder arrangement, the minimum temperature that will cause an explosion is 970°F, corresponding to a compression ratio of 27.6. This applies to a mixture of 50 percent hydrogen-50 percent oxygen by volume and is independent of the initial pressure within the limits of one to three atmospheres.

For hydrogen-rich mixtures, the minimum explosion temperature rises rapidly. For example, a mixture consisting of 20 percent oxygen-80 percent hydrogen has an ignition temperature of 1160°F.

For oxygen-rich mixtures, the minimum temperature again rises and is 1070°F for a 20 percent hydrogen-80 percent oxygen mixture.

• • Ortho-Para Conversion

An interesting but somewhat inconvenient property of hydrogen, called the ortho-para conversion, must be considered by the rocket engineer. The hydrogen molecule has two distinct energy states, called ortho-hydrogen and para-hydrogen. The proportion of the two forms is a function of the temperature, lower temperatures favoring the presence of para-hydrogen in

an equilibrium mixture. At room temperature, the equilibrium mixture, called normal hydrogen, contains 25 percent para-hydrogen; at the boiling point of nitrogen (-320°F), the mixture contains approximately 50 percent para-hydrogen; and at the boiling point of hydrogen (-423°F), the mixture contains 99.8 percent para-hydrogen. When the temperature of hydrogen is changed, the proportion of ortho- and para- molecules also changes; but the change is fairly slow, especially in the gas phase. Therefore, during liquefaction of hydrogen, there is very little conversion to the para-form, and the freshly liquefied gas is still nearly three-fourths ortho-hydrogen.

When liquid hydrogen is stored, conversion to the para-form occurs with the liberation of 304 btu/lb. This quantity of heat is considerably larger than the latent heat of vaporization (194 btu/lb), and therefore a large fraction of the hydrogen will be vaporized during conversion if no means is provided to remove the heat of conversion. Even if the liquid could be protected from every source of external heat, about 65 percent of it would boil away because of this internal liberation of heat by the time it had converted completely.

• • Hydrogen Liquefaction

Up until the last few years, the method for liquefying hydrogen consisted of cooling highly compressed hydrogen by heat exchange with boiling liquid air or nitrogen and then expanding the hydrogen through a valve or orifice from a pressure of approximately 2000 psi. This system is commonly called the high pressure system or the Joule-Thomson System. As low temperature experience was being gained, some members of the Arthur D. Little staff realized the possibility of developing low pressure hydrogen liquefaction and storage systems that would be simpler, lighter, safer and more adaptable to field use than the older methods. Some of these ideas stemmed from the experience gained in the development and construction of helium liquefiers, such as the ADL Collins Helium Cryostat.

Figure 1 shows a complete ADL Collins Helium Cryostat unit, with liquefier cabinet, compressor, gas holder and helium purifier. The main purpose of this

Table 1. Comparison of Liquid Oxygen and Liquid Hydrogen Properties.

	Hydrogen	Oxygen
Boiling Point (atm. press.)	-423°F	-297.6°F
Freezing Point	-436°F	-361.8°F
Critical Temperature	-400°F	-181.8°F
Critical Pressure	13.5 atm	4.7 atm
Density	4.43 lb/ft ³	71.1 lb/ft ³
Heat of Vaporization	194 btu/lb	92 btu/lb

machine is to supply liquid helium (B.P. -452°F) for experimental use in scientific research laboratories. An auxiliary liquefying system is included for liquefying almost any other gas, such as hydrogen, neon and nitrogen. To liquefy hydrogen, helium is circulated at all times in the gaseous state and the cold end of the system is maintained at a temperature somewhat below the liquefaction point of hydrogen (-423°F). The hydrogen, at slightly above atmospheric pressure, is cooled by heat transfer and is liquefied at the cold end of the system. Hydrogen can be liquefied in quantities of from 1 to 2½ gallons per hour in this unit.

In addition to supplying liquid helium, many of these units are regularly used for liquefying hydrogen. The units can be set up and a technician can be trained in its operation in a matter of a few days. Although the Cryostat was designed for laboratory use, one unit has been mounted on a truck and operated in the field.

Based on the helium liquefier experience, it appeared that refrigeration equipment, specifically designed for the liquefaction and/or the recondensing of gas from boiling hydrogen, could be developed. This type system would provide means not only for liquefaction, but also for no-loss storage and transport. An experimental prototype was built and operated for several thousand hours. The results were promising enough to indicate the feasibility of such systems.

● ● Large-Scale Requirement for Liquid Hydrogen

Under Government sponsorship, several helium-refrigerated, liquid hydrogen transport vehicles were built. Figure 4 is a simplified flow diagram of the refrigeration system.

The liquid hydrogen container (dewar) on these transport vehicles is a vacuum-jacketed tank with a capacity of about 530 gallons. The inner shell of the dewar is stainless steel and is suspended by two sets of cables inside an outer steel vacuum shell. The space between these two shells is maintained under vacuum for thermal insulation. Further thermal isolation is provided by a cooled radiation shield that is suspended between the two shells.

The very small rate at which heat leaks through the vacuum insulation and the radiation shield, plus the rate of heat generation by ortho-para conversion within the liquid hydrogen, is offset by use of a helium refrigeration system. Heat is removed from the dewar by circulating cold helium gas through condensing coils attached to the refrigerator. These coils are mounted above the surface of the liquid hydrogen in the upper part of the inner shell of the dewar. Some of the hydrogen vapor there condenses on the coils and drops back into the liquid. The hydrogen vapor pressure is maintained at a few pounds above atmospheric pressure by having the refrigerator operate intermittently.

The refrigerator is connected to the dewar through a vacuum-insulated coupling. The refrigeration cycle

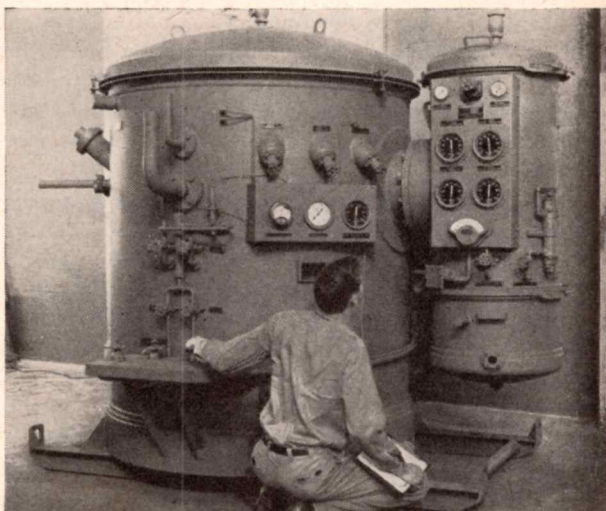


Figure 4 — Installation of low-pressure helium-refrigerated hydrogen liquefying and storage systems.

Table 2. Possible Propellant Combinations of Hydrogen

	Oxidizer/Fuel Ratio	Combustion Temp °F	Theoretical Specific Impulse (300 psi, 14.7 psi)	Bulk Sp.Gr.
Hydrogen-Fluorine	9.42	8072	371	0.457
	3.77	4469	356	0.269
Hydrogen-Ozone	2.65	4280	373	0.23
Hydrogen-Oxygen	2.89	3886	345	0.23
Hydrogen-WFNA	12.6	5360	298	0.60
Hydrogen-Nitrogen Tetroxide	11.5	5610	279	0.565
(Ethyl Alcohol-Oxygen)	(1.50)	(5297)	(242)	(0.970)

Table 3. Power Requirements for Low and High Pressure Hydrogen Liquefying Units—KWH/Gallon Liquid H₂.

Plant	Description	Normal H ₂	Para H ₂
A	H ₂ , High Pressure (includes power for liquid nitrogen plant and vacuum pumps)	7.82	10.45
B	H ₂ , Low Pressure (without use of any auxiliary refrigerant since expansion engines are used)	2.45	3.5
C ₁	Low Pressure (using helium and freon for refrigerants)	3.65	5.2
C ₂	Low Pressure (using helium and freon for refrigerants and including power to compress hydrogen)	4.02	5.55

used in the helium refrigerator is based on cooling with expansion engines. In the compressor section, the helium is compressed to about 220 psig by two single-stage, motor-driven compressors, arranged in series, with an inter-cooler and an after-cooler to remove the heat of compression. This heat is dissipated by an air-cooled radiator from cooling water that flows through the compressors and coolers.

The two expansion engines and heat exchanger for cooling the helium are mounted in a vacuum shell, called the cold box, beneath which is a housing for the crankshafts of the two engines and a hydraulic pump. The heat removed from the helium gas in the expansion engines is transmitted as mechanical work by the pistons to the hydraulic pump. The heat thereby generated in the hydraulic pump is eventually transferred to the cooling system.

Cold helium gas from the expansion engine is delivered through the helium coupling to the condensing coil in the dewar at about 43 psig and about -432°F, some ten degrees below the hydrogen boiling point. In the condensing coil it warms up to about -423°F, at which temperature it returns to the cold box. In the low-pressure side of the heat exchanger, it is warmed to approximately atmospheric temperature for delivery back to the suction side of the compressor. Initially, the equipment used liquid nitrogen for cooling the radiation shield. But modifications in the equipment and operating procedures were made so that the helium refrigerator could supply the cooling for the shield. This made the units essentially self-sufficient in the field.

● ● New Equipment

Figure 3 is a flow diagram of a helium-refrigerated, hydrogen liquefying and storage system. The entire helium circuit is essentially of the same design as described previously and is of such construction that it will retain the fixed helium charge for long periods of time, variation in volume due to temperature change being taken care of by an expansion tank.

Since the gas is to be liquefied, some additional heat exchangers, not present in a refrigeration design, are

required. The hydrogen from gas bottles, or a similar source at low pressure, passes through the heat exchanger and is liquefied at the condensing coil. The liquefier is designed to accommodate cylinder gas of commercial purity without the use of auxiliary purification steps, such as the liquid nitrogen cooled absorption trap customarily used in hydrogen liquefiers. Final purification is accomplished by a freeze-out process in a duplex exchanger system within the liquefier. Experience has shown that this method of final purification gives good results when using commercially available electrolytic hydrogen and that it is necessary to shift from one side of the duplex freeze-out system to the other approximately once for each eight hours of operation, depending on the purity of the hydrogen supply. The equipment is so arranged that this shift can be made and the fouled freeze-out exchanger can be derimed without interruption of the liquefaction process.

Similar heat exchangers have been designed for the catalytic conversion of the hydrogen before it is liquefied. Catalytic conversion can be carried out when the hydrogen has been liquefied. However, this method is not as thermodynamically efficient as gradual conversion in the gas phase. Depending upon the degree of conversion, both evaporation losses in storage containers and liquefaction rates are thereby decreased.

Since all of the gas supplied to the unit is liquefied as it passes through the system, there is no requirement for recompression of effluent process gas. Thus, the possible sources of contamination of the gas, or loss of it through leaky stuffing boxes and the like, are essentially eliminated. Also, the hazards associated with the compression of a flammable gas are not present in this liquefier. A built-in liquid receiver of about 200 gallons capacity facilitates accumulation of liquid in substantial quantities without incidental evaporation losses. Thus, liquid hydrogen, in any amount up to 200 gallons, may be drawn off in a single continuous transfer operation at the built-in transfer connection.

Storage of liquefied gas can be carried out indefinitely in this helium-refrigerated, liquid receiver without any loss of gas by evaporation. This eliminates the need for close correlation of the time schedules for preparation of liquefied gas with its use. In effect, liquid is ready "on tap."

If the liquid hydrogen is to be stored for a period of time before transfer, the helium refrigeration system may be used intermittently to remove the heat generated by ortho-para conversion of hydrogen and the heat transmitted by conduction to the receiver, thus preserving the liquid without loss.

Figure 4 shows a sketch of an installation of low-pressure helium-refrigerated hydrogen liquefying and storage systems. The low pressure helium compressors and electrical equipment are in the room with the operator for ease of operation and safety. Also, during start up, test runs and operator training, the unit can be operated without having flammable hydrogen in the vicinity. Since the electrical equipment is isolated from any possible hydrogen atmosphere, ordinary

wiring can be used, thus contributing to the reduction in cost and complexity of the installation. Also, since part of the building need only be a louvred outdoor shelter, the building can be relatively inexpensive in construction. Heating costs are reduced and ventilation is not affected should an unexpected loss of power occur. If it were desired to produce liquid hydrogen in the field, such a unit could readily be mounted on a trailer or railroad car.

The point may be raised that hydrogen liquefaction by the helium refrigeration method is not as thermodynamically efficient as the so-called high pressure system. Plant C₂ in Table 3 shows that the helium system requires only one-half as much power per gallon of liquid.

● ● Liquid-Hydrogen Transfer Methods

Before liquid hydrogen is transferred from a storage dewar into any other piece of equipment, it is important to insure that the other components are free of any oxygen. A definite purging procedure should be set up and used. Usually, a combination of evacuation and flushing with an inert gas such as helium is feasible. The receiving vessel and the transfer lines can be pre-cooled with liquid nitrogen and then purged if their heat capacity is high. Usually, only the receiving vessel itself would be pre-cooled, but in some of the rocket installations the length of transfer lines may be so long that the liquid hydrogen loss would be excessive. The transfer lines usually are insulated by high vacuum jackets with thermal radiation shielding. A typical line with a $\frac{3}{4}$ inch inside diameter has approximately 0.6 btu/hr per foot of length heat leak.

After the transfer system has been connected up, pre-cooled and purged with helium and finally hydrogen gas, the pressure over the liquid in the storage dewar is increased. The pressurization is done in such a manner that the liquid is heated as little as possible. This can be done by using an external source of gaseous hydrogen or by removing a small amount of liquid from the dewar and boiling it to yield the pressurizing gas. If the entire mass of liquid is heated until the saturation pressure reaches the required transfer pressure, additional unnecessary flashing losses will occur.

There will, in any case, be some liquid loss in a simple transfer system, due to the relatively warm lines and dewar (even at -320°F), heat leakage and flashing of the liquid as the pressure is reduced. If the situation warrants additional complication, and no-loss transfer is desired, a helium refrigerated condensing coil can be used in the receiving dewar. By this method, the transfer of liquid hydrogen can be accomplished between two vessels with essentially no hydrogen gas escaping in the process. A system such as this might be advantageous if the situation requires no loss of hydrogen gas to the surroundings.

● ● Conclusions

Hydrogen has the following properties that rocket engineers must take into consideration when deciding on methods of liquefaction and storage:

- 1) Inflammability.
- 2) Wide explosion limits of hydrogen-air mixtures.
- 3) If compressed to high pressure (say 2000 psi), there is the hazard of rupture of equipment, which is dangerous in itself, but which also may set off a chain of other hazardous events, such as explosion or fire.
- 4) Spontaneous combustion of hydrogen-air mixtures above 970°F .

The helium refrigerated systems reduce the potential hazards, mentioned above, as follows:

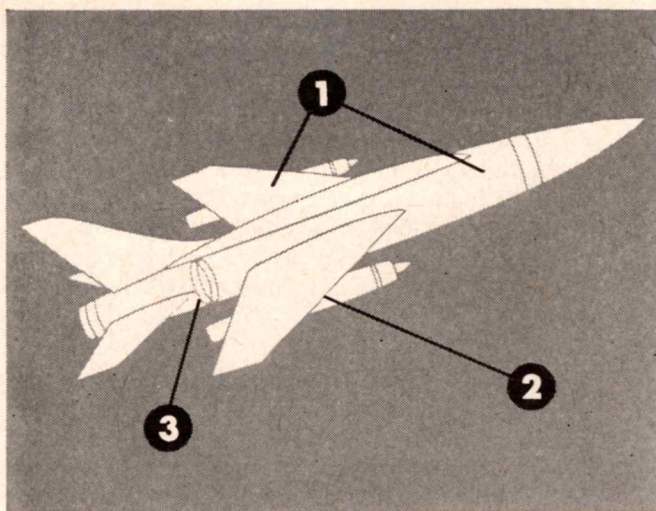
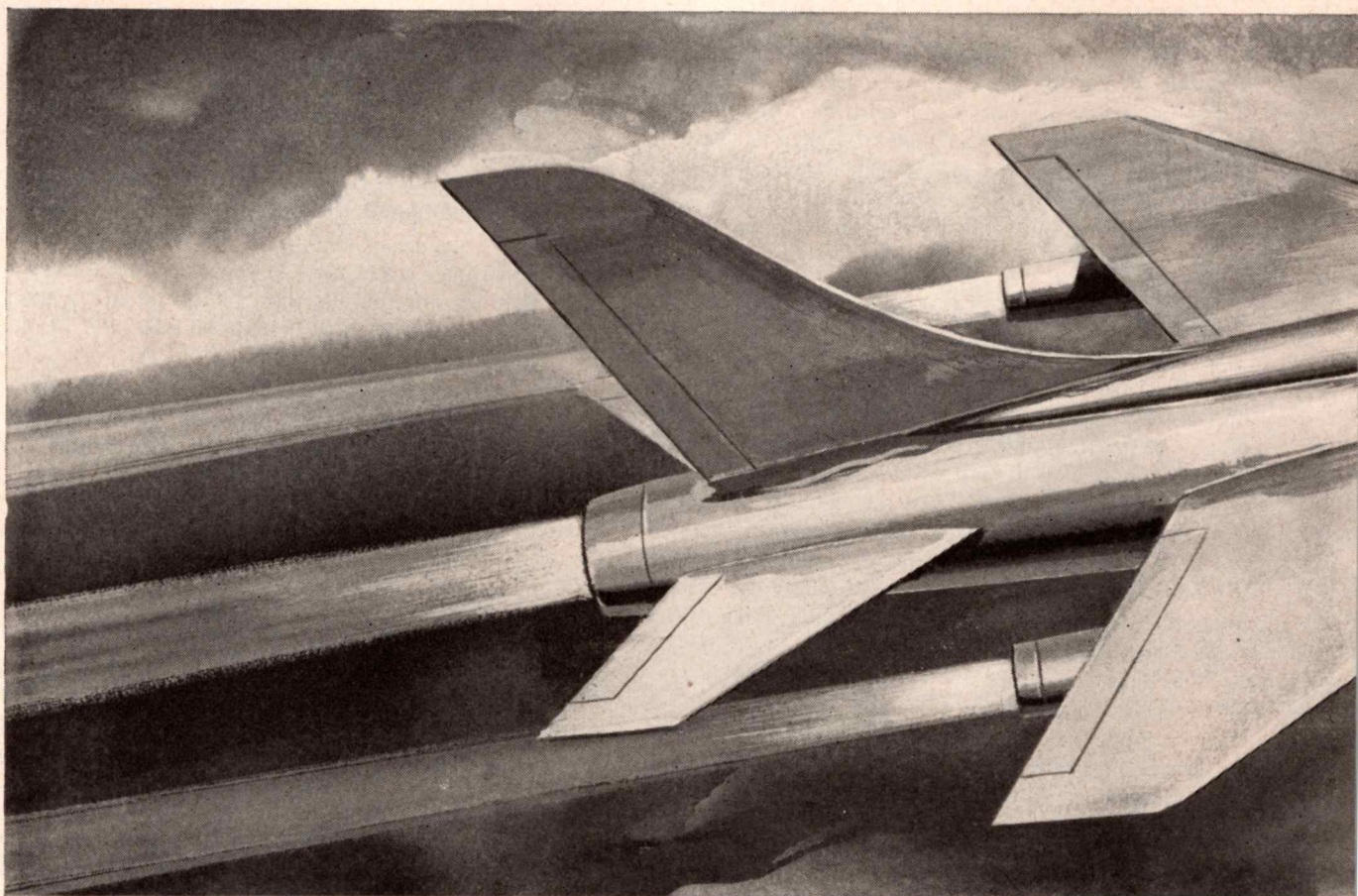
- 1) The equipment can be cooled down, test operated and maintained without the use of any hydrogen.
- 2) Hydrogen is not used in the refrigeration cycle, thereby eliminating the chance of air getting into contact with hydrogen in this part of the cycle.
- 3) The hazards of equipment rupture are essentially eliminated. The hydrogen in the system is only slightly above atmospheric pressure, and the helium pressure is about 225 psi.
- 4) The problem of spontaneous combustion is eliminated as the hydrogen is not under compression.

The knowledge and experience gained from the development work and construction of the equipment described here, indicates the feasibility of adapting these units to almost any low boiling liquefied gas for missile powerplants or other special uses. In addition to the safety aspects, another advantage of the helium refrigerated systems is that no auxiliary refrigerant, such as nitrogen, is needed, whereas the classical high-pressure system requires liquid nitrogen to refrigerate the hydrogen below the Joule-Thomson inversion temperature. This advantage has a practical aspect: the field supply problems and the liquefaction equipment transportation problems are all reduced.

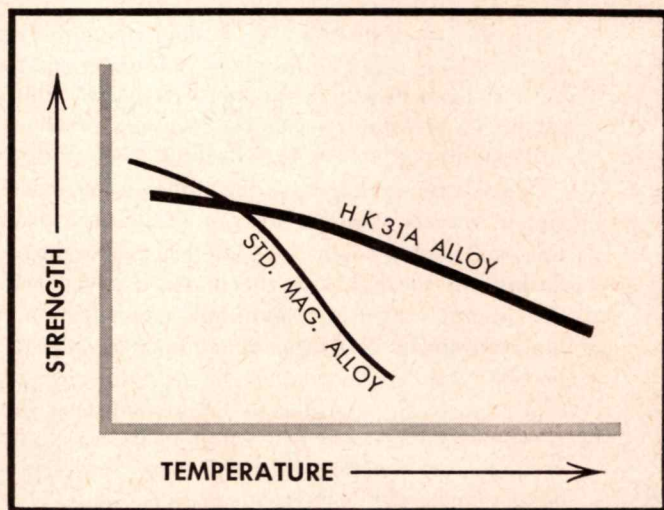
With the helium refrigeration system, there are several possible plant set-ups for actual field use. It is feasible to erect a large stationary plant at a convenient location to serve as a central fuel supply and storage station. When fuel is needed, the fuel could be transferred to helium-refrigerated trailers and transported by highway or rail to advance bases. If necessary, these liquefied gases could be transported, unrefrigerated, by air, with helium refrigerators available at the destination. Another possibility is to construct plants, suitable for transport by air, road or rail.

For tonnage capacity plants, a high thermodynamic efficiency is advantageous since it will result in low power consumption; the helium refrigeration method will not achieve the highest efficiency and, therefore, a cycle which compresses and expands hydrogen directly is required; the refrigeration required may be obtained by suitable choice of cascade refrigeration for the auxiliary refrigeration and hydrogen turbo expanders and Jule-Thomson valves for the remaining refrigeration at the temperature level below that furnished by the auxiliary source. ♦ ♦

NEW DOW MAGNESIUM ALLOYS

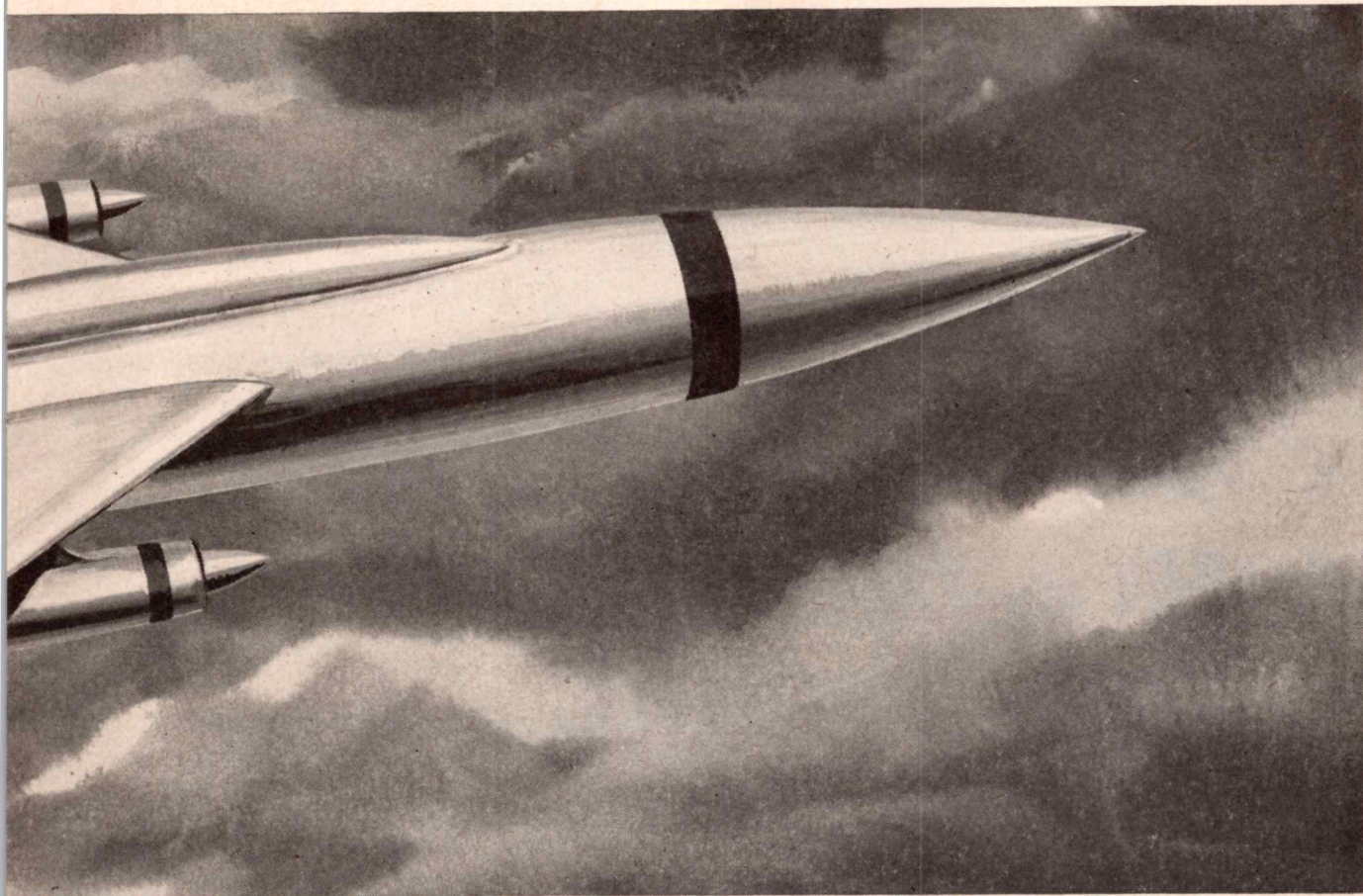


Now suggested for a broad range of uses in missiles and aircraft, the new Dow magnesium alloys are available in the form of (1) sheet or plate, (2) extrusions, (3) castings.



Maintenance of strength at high temperatures is illustrated by this chart. Performance data on the new alloys at elevated temperatures can be obtained by request.

CRACK HEAT BARRIER!



High temperature magnesium alloys are available to lighten aircraft and missile structures

Once again the horizons for aircraft structural design have been widened. Dow has developed a series of high temperature magnesium alloys which are already in pre-production use on aircraft, missile and engine structures. These alloys show advantages at temperatures up to 700° F. Limited test data on properties up to 800° F. are available for some of these alloys.

The new alloys save precious pounds because of their good combination of modulus and properties, including creep strength, at temperature. Shop characteristics include good formability and weldability.

One of the available alloys is the magnesium-thorium composition, HK31A, which is manufactured in rolled and cast form. Under development is a similar alloy for extruded shapes and forgings. HK31A sheet and plate are available from stock and from current mill delivery schedules in standard sizes from 0.016" to 2".

These new magnesium alloys by Dow should be considered for your high temperature requirements. Contact your nearest Dow sales office or write THE DOW CHEMICAL COMPANY, Magnesium Sales Dept., MA 361EE, Midland, Michigan.

you can depend on DOW MAGNESIUM

DOW

Today the jet-engine choice is either the turboprop or the turbojet. Tomorrow, the turbofan enters the picture.

Criteria for Using

TURBINE POWERPLANTS IN LIGHT AIRCRAFT

GILBERT L. ROTH

Senior Propulsion Engineer,
Convair (Fort Worth)
Division General Dynamics Corp.

THE PHRASE "LIGHT AIRCRAFT" applies generally to military and civilian fixed-wing aircraft with a maximum gross weight up to 16,000 pounds, a subsonic speed range and an operational altitude up to approximately 35,000 feet. Gross weight limitations can be subdivided as follows:

Transport aircraft: gross weight 8000 to 16,000 pounds; trainer aircraft: gross weight 2500 to 8000 pounds; utility aircraft: gross weight 2500 to 8000 pounds.

As defined, the light aircraft require turbine engines with thrusts up to 2500 pounds and shaft horsepower up to 1500 horsepower. Of the engines now in production approximately 25 percent of the turboprops and 15 percent of the turbojets are applicable to the light plane. (Turbofan engines are new developments and have not reached a useful production status.) The root of this powerplant deficiency is simple and straightforward. Ever since the initial development of the gas-turbine engine, the emphasis of research and development groups has been towards higher gross thrusts in turbojets to the exclusion of low-thrust turbojets and all types of turboprop engines.

What value of thrust and shaft horsepower do the various types of light aircraft require? The first case is that of a lightweight trainer of about 2500 pounds gross weight. The thrust and horsepower requirements are approximately 450 pounds and 250 SHP, respectively, for a condition of V_{max} at sea level of 160 mph. At sea level static conditions the power requirements are 900 pounds of thrust and 250 SHP (take-off conditions).

For a single-engine jet trainer of 6000 pounds gross weight, a J-34 engine with a static thrust rating of 3250 pounds can be used. The J-34, of course, is an old design and does not have the thrust-to-weight ratio that the newer engines can give.

A 12-passenger transport aircraft might incorporate two Mamba III turboprop engines with an equivalent shaft horsepower per engine of approximately 1500 SHP; the same requirements in the turbojet installation would be nearer 4500 pounds thrust per engine.

This gives us the background necessary to permit a more complete evaluation of the problems involved

in the application of turbine powerplants to light aircraft. The following points must be considered:

- 1) Turboprop or turbojet powerplant?
- 2) Weight problems associated with each of the turbine powerplant types.
- 3) Short field takeoff and landing, including the use of after-burning engines and thrust reversal.
- 4) Air-inlet and gas-exhaust design.
- 5) Application of turbofan engines.

There are many other problems such as those dealing with engine cooling, anti-icing, fire suppression and engine controls.

• • Turboprop or Turbojet Powerplant

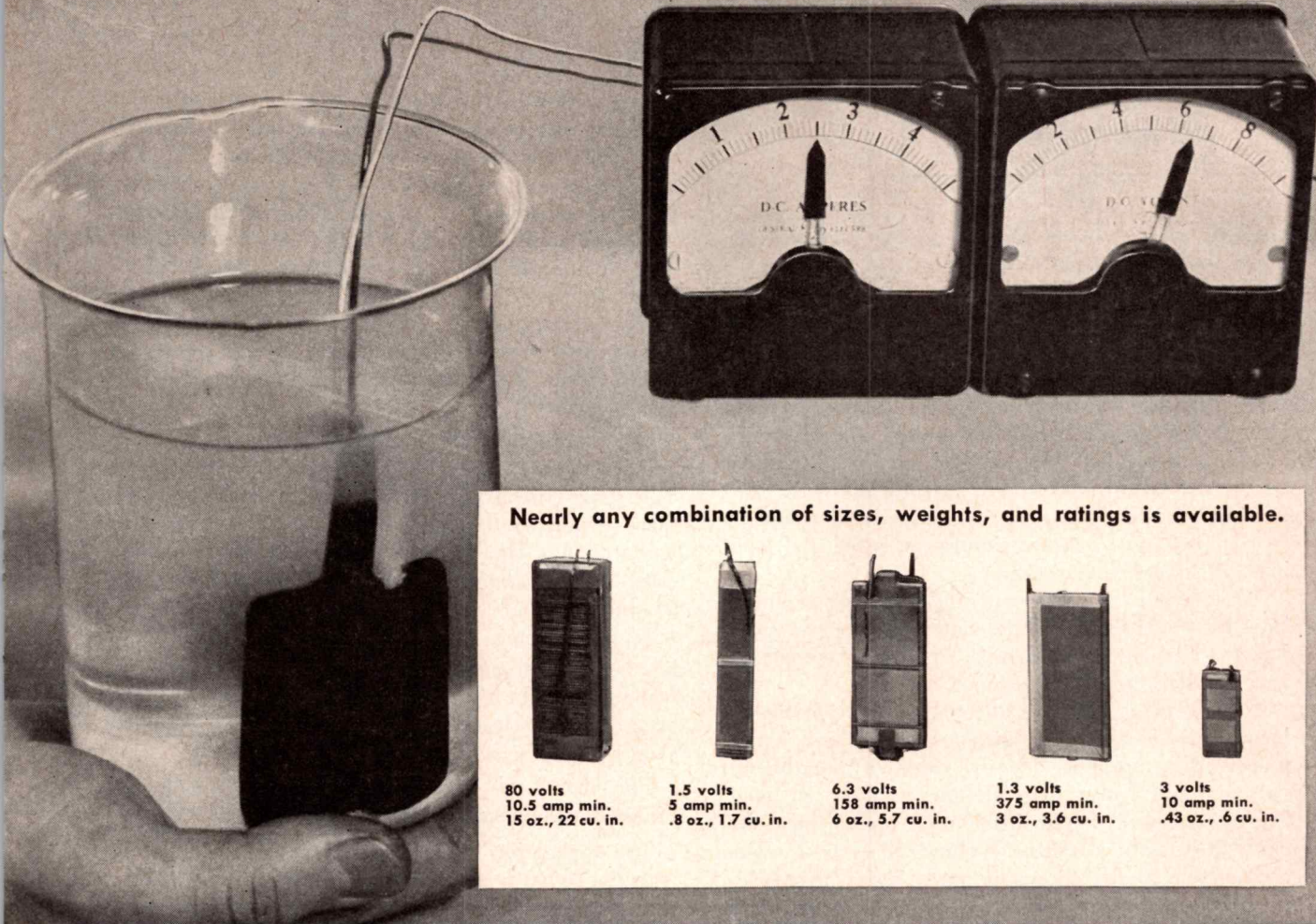
Present thinking has relegated the turboprop to the speed range between Mach 0.3 to 0.8; the turbojet from 0.5 to the supersonic. These limits are actually quite flexible since other factors may be of greater importance. The advantages of the turboprop engine are:

- a) Low engine plus fuel weight owing to low SFC and relatively low engine weights.
- b) Shorter takeoff distance possible.
- c) Desirable flight altitudes: from sea level to 35,000 feet.
- d) Shorter landing distances possible with little or no increase in weight.
- e) Relatively high cruising power which permits a high speed at low SFC thereby giving the turboprop aircraft a high specific range (miles/lb fuel).

The advantages of the turboprop make it most adaptable to the lower speed, medium-altitude light

Table 1. Weight Comparison

	Gross Weight (%)	
	Turboprop	Turbojet
Propulsion Group (engine, accessories, etc.)	20	15
Fuel Group (fuel, tanks, pumps, etc.)	26	44
Structural Group	31	28
Payload, communications & electronic equipment, etc.	23	13
	46	59



Nearly any combination of sizes, weights, and ratings is available.



80 volts
10.5 amp min.
15 oz., 22 cu. in.



1.5 volts
5 amp min.
.8 oz., 1.7 cu. in.



6.3 volts
158 amp min.
6 oz., 5.7 cu. in.



1.3 volts
375 amp min.
3 oz., 3.6 cu. in.



3 volts
10 amp min.
.43 oz., .6 cu. in.

SHOWING TREMENDOUS POWER FOR RELATIVE WEIGHT, THIS 3-OZ. BATTERY DELIVERS 2.5 AMPS AT 6.3 VOLTS FOR 16 MINUTES.

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tery, investigate G.E.'s line today. And remember, though a wide range of ratings and sizes is available, G-E water-activated batteries can be designed to your specific needs. For detailed information, contact your G-E Apparatus Sales Office, or send coupon below for free descriptive bulletin.

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Powerplants

aircraft. The turbojet would best be used for the high-speed light aircraft in which range is kept to a minimum. Probably the biggest drawback to the turbojet is the high SFC which requires an increase in fuel tank capacity, structural size and large quantities of fuel, all of which compromise the light-aircraft gross weight. In terms of the three classes of light aircraft defined previously, the trainer aircraft seems most adaptable for the turbojet engine, while for transports the turboprop is apparently the best. For the case of utility aircraft, the engine used would be based upon three factors: endurance, speed and landing and takeoff distances.

In addition, the initial cost and servicing would be least for the turbojet as the combined propeller gearing and turbine powerplant is of greater complexity and requires more maintenance.

The aircraft weight, as affected by the type engine installation, has to some extent been covered in the preceding paragraphs. Actual values of weights involved might better illustrate the problem at hand. The comparative weight distribution for a typical aircraft, with identical ranges, is shown in Table 1. This comparison readily shows the tremendous increase in fuel for the turbojet with only a small reduction in propulsion-group weight. There is also the safety angle associated with the increased fuel required for the turbojet since crash fires are dependent upon fuel spillage rates, fuel tank areas, and total quantities.

An additional weight advantage on the side of the turboprop, especially for light aircraft, is the reverse thrust and feathering available from a variable pitch propeller. The weight necessary to use this feature is small compared with the equipment needed on a turbojet for the same reverse thrust.

• • Short Field Takeoff and Landing

Generally speaking, the light-aircraft manufacturer is interested in reasonable short-field takeoff and landing distances. Table 2, prepared for a single-engine aircraft, illustrates the distances involved.

Table 2. Takeoff and Landing Distances.
(50-ft obstacle)

	Turboprop-280 SHP (Artouste-1)	Turbojet-920 lb (Marbore 352)	Reciprocating 225 SHP (Continental)
Gross weight, lb	2900	3500	2800
Takeoff over 50 ft obstacle.			
NACA std. day, sea level, ft	1220	2190	1650
100°F day, sea level, ft	1970	3000	2290
Landing over 50 ft obstacle.			
NACA std. day, sea level, ft	1585	2010	1540

In the case of the turbojet aircraft, the equipment necessary to reduce the landing and takeoff distances would be too large insofar as weight is concerned. The afterburner, when used to reduce takeoff distance, would weigh about 100 pounds. This weight, in flight, would be useless, and the additional fuel used would only complicate the weight and structural problem. Water injection is in about the same category as the afterburner excepting for a lesser cost in weight. Thrust-reversal units for reduced landing distances would again have the same disadvantages of weight and complexity.

For a turbojet transport, there might be some advantage to using one of the devices mentioned above. The weight involved, for instance, is of less importance owing to the overall increase in aircraft size and weight. The use of such devices would in this case, of course, be dependent upon the required design conditions.

In the last few years, the use of high-lift devices has been investigated and found desirable for use on takeoff for light aircraft. In this view, therefore, the need for water injection and afterburning is lessened even more.

For short-field landings, the use of present day brakes for the small aircraft is usually sufficient.

The application of turbine engines is tied in closely with the actual powerplant installation possible with a given aircraft. For the turbine engine, the pressure recovery available at the engine inlet is of primary importance. The power output varies at more than a one-to-one ratio such that an inlet pressure loss of one percent will cause a reduction in thrust and power output of 1½ to 2 percent. For a one percent loss through the exhaust ducting the thrust and power output will be reduced from ½ to 1½ percent.

The design of engine inlets for subsonic aircraft is a relatively simple matter. The only points to be remembered are:

- 1) Large enough inlet flow area to accommodate required airflow at all conditions.
- 2) Achieve item (1) with minimum drag and maximum pressure recovery at the design flight conditions.

In light aircraft, the two-engine installations normally used are within the wing and fuselage side. Pods are not used because of either weight or geometric considerations.

The turbofan engine has only begun to reach the period of development where production aircraft may make use of its possibilities. At this time the turbofan appears to be applicable to both large and small aircraft. The turbofan is essentially a turboprop engine in which the propeller has been reduced in diameter and the basic engine outer shell extended beyond the propeller to form a duct around it. Thus the propeller is now a low-pressure compressor putting air into a duct that surrounds the basic engine. The turbofan engine may well outclass the turboprop and pure turbojet powerplants in future applications. ♦ ♦

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Knowledge of or experience in dynamics, stress analysis, servomechanisms, heat flow and circuit analysis or non-linear mechanics is helpful.

Boron and Its Effects in Alloy Steels

Boron is a nonmetallic element of which this country has a plentiful supply. In its natural or unprocessed state it occurs only in combination, as in borax, etc. Pure boron is a gray, extremely hard solid with a melting point in excess of 4000 deg F.

This element is used in steel for one purpose only—to increase hardenability; that is, to increase the depth to which the steel will harden when quenched. Its effective use is limited to sections whose size and shape permit of liquid quenching. Only a few thousandths of 1 pct is ordinarily added, and boron steels are evaluated by increased hardenability rather than chemical content. A number of alloys, including several grades of ferroboration, are available for adding boron to steel.

Boron intensifies the hardenability characteristics of other elements present in the steel. It makes possible a considerable degree of alloy conservation when used with steels containing small amounts of alloying elements. However, since it readily oxidizes at high temperatures, some steelmakers prefer a melt with relatively low boron content and relatively high contents of other elements that protect the boron from oxidation.

It should be noted that boron is very effective when used with low-carbon alloy steels; but its effect is reduced as the carbon increases. When the carbon content is above

0.60 pct, the use of boron is not suggested, the exception being the "case" in those steels that are carburized.

Boron steels often require closer temperature control in heat-treatment than do some of the other alloy analyses; but aside from this they present no special problems. Their cold- and hot-working properties are considered at least equal to those of ordinary alloy steels. In cases where boron makes possible a lower alloy content, improved machinability frequently results.

If you would like to know more about boron and its effects in alloy steels, you are invited to consult with Bethlehem's metallurgical staff. Our technicians will gladly give you all the information you need, and will work closely with you in every respect. And when it is time to replenish supplies of steel, remember that Bethlehem manufactures the full range of AISI standard alloy grades, as well as special-analysis steels and all carbon grades.

If you would like a reprint of this advertisement, or of the entire series from I through XV, please write to us, addressing your request to Publications Dept., Bethlehem Steel Company, Bethlehem, Pa.

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BETHLEHEM STEEL

For further information circle Reader Reply No. 8



Rascal "no time over the target"

High in the atmosphere, a huge U.S. Air Force bomber wheels. As it changes direction, a long shape separates from the bomber. Rocket engine firing, the shape accelerates to high speed and vanishes into the distance... an air-to-surface missile on its swift way to a far-off target.

This, in brief, is the mission of the GAM-63 Rascal guided missile—designed, developed and produced for the U. S. Air Force by Bell Aircraft Corporation.

Rascal is a long range, air-to-surface missile which accomplishes its mission without exposing the bomber aircraft to concentrated local defense. Rascal can be launched and proceed to its destination while the bomber is on its homeward flight, thus sparing aircraft and crewmen the critical "time over the target."

The guidance system which controls Rascal is close to human intelligence and operates just as if a pilot were riding in the nose of this missile. Rascal is propelled at its tremendous speeds by a rocket engine also developed by Bell.

Rascal encompasses one of the broad concepts of Air Force missile programming and Bell Aircraft has applied all the skills of its vast scientific and engineering team in the development of this strategic weapon system.

The Air Force-Industry team urgently needs scientists and engineers for projects vital to the nation's defense. Opportunities to make important contributions are offered in military or civilian careers.



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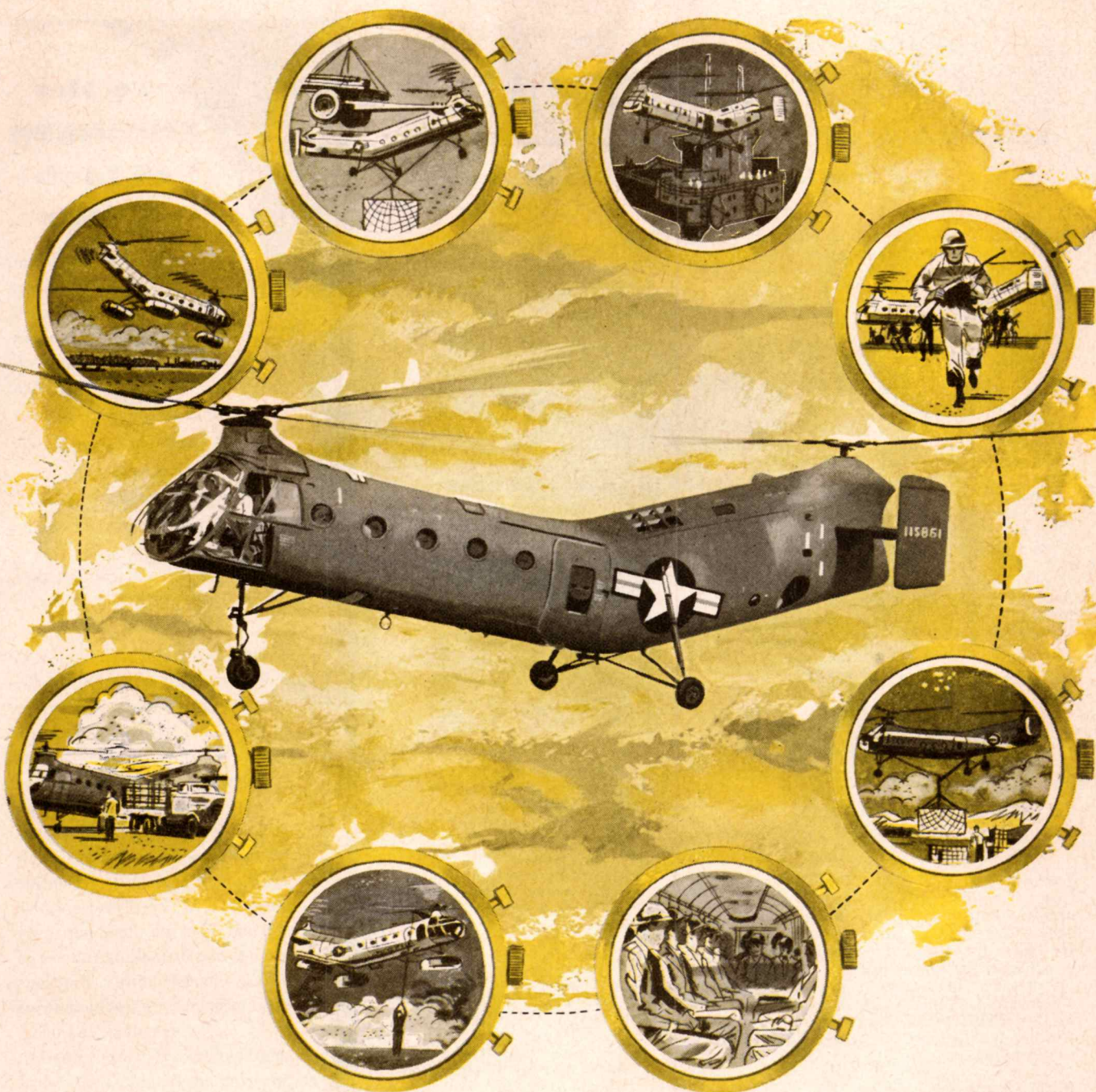


Lower weight giving increased payload
Lower guaranteed specific fuel consumption
Lower first cost and operating costs
Less noise



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out of reach of other vehicles. Bulk equipment is airlifted—flying crane fashion—over rivers and mountains.

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Around the clock, around the world, Vertol helicopters are being picked again and again for the toughest jobs.

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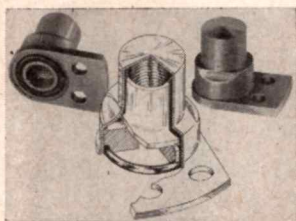
For further information circle Reader Reply No. 40

new equipment

For further information use Reader Reply Card on Page 65.

Isolator. Kearfott Company, Inc. displacement absorption ferrite isolator, Model 165-1A, for 8800 mc, 50 watts average power, with 25 db isolation and 0.25 insertion loss, involves new resonance absorption technique. Can be designed for an Xband frequency and will handle 50 KW peak power. Weight 12 oz — insertion length 1.9 in. (E-13)

Screwjack Actuators. A lightweight series of screwjacks for aircraft and missiles, suitable for applications requiring actuation of components such as wing and cowl flaps, vent doors, drag brakes and canopies, has been developed by Southwestern Industries, Inc. Actuators incorporate rotary input with double-ended spined shaft permitting use of several units in series, linked by flexible couplings. Operating temperatures range from -65°F to $+275^{\circ}\text{F}$. (E-15)



Locknut. Elastic Stop Nut Corporation of America has introduced a new one-lug cap seal anchor locknut, designed for integral aircraft fuel tanks in which space for riveting is limited or where bolt holes are close together. Despite its light weight and reduced size, ESNA Type A2507 conforms to MIL-N-25027 (ASG) requirements for torque, tensile, twist-out and push-up performance. (E-16)

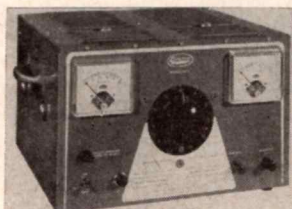
Rotary Inverters. VARO Mfg. Co. announces a complete line of precision-frequency rotary inverters for aircraft and missile applications, available with outputs ranging from 250 to 3500 volt-amperes. Inverters hold output frequency to within 0.1% of 400 cps despite varying load and input voltage conditions, according to manufacturer. (E-17)

Air Gage. New radial play air gage, for simplifying and speeding checking of internal clearances between inner and outer rings of ball bearings, uses controlled air stream to do the measurement job. The Sheffield Corporation. (E-18)

Switch. A sealed, roller plunger, high-capacity switch that will handle inrush currents as high as 75 amperes has been introduced by Micro Switch, a division of Minneapolis-Honeywell Regulator Company. Manufacturer says switch is made oil-tight by special integral O-rings around the bushing and plunger and a ring-type

seal between the cover and the housing. (E-20)

Printed Circuit Kit. Photocircuits Corporation has developed a complete kit for production of engineering or prototype models of printed circuit parts. Kit is composed of drawing pen and etchant resist ink, 4 bottles of etching powder, a drawing guide, 10 copper laminated Bakelite sheets, 10 most popular tube sockets and detailed instructions for use. Manufacturer says at least a dozen circuits may be produced with materials in the kit. (E-21)



Power Supply. Model "NFA" d-c power supply, newest offering by Electro Products Laboratories, features less than $\frac{1}{4}\%$ ripple at a top load of 15 amps, a circuit breaker, full view meters, pilot light and carrying handles. Provides continuously variable source for voltages from 0 to 32 volts for all current loads from 1 to 15 amperes. (E-19)

Rectangular O-Rings. Four rectangular metallic O-rings, each measuring more than 7 ft. 2 in. x 3 ft. 7 in., have been produced by United Aircraft Products, Inc. Manufacturer says the rings, which are used to seal the casing joints of a 5000-gallon-a-minute pump, are the largest of their kind in the world. The $\frac{1}{4}$ in. tubing has a wall thickness of 0.032 in. (E-22)

Cooling-Effect Detector. Aviation Products Division of Fenwal Incorporated has developed a cooling-effect detector designed to detect inadequate cooling of air-cooled electronic components. Unit senses the combined cooling effect contributed by both ambient temperature and mass rate of air flow. Called Series 18801 Thermo-switch, it can be connected to an alarm device or, by suitable relay, control solenoid- or motor-actuated valves to produce the additional cooling action required for an over-temperature conditions. (E-23)

Terminals. New and complete line of stand-off and feed-through terminals is now available in a full range of sizes from Whitso, Inc. Offered in fork, single and double turret and miniature types, male or female threaded or with rivet mountings.

To the ENGINEER of high ability

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For further information regarding opportunities in the Los Angeles, Phoenix and New York areas, write today, including a resumé of your education and experience.

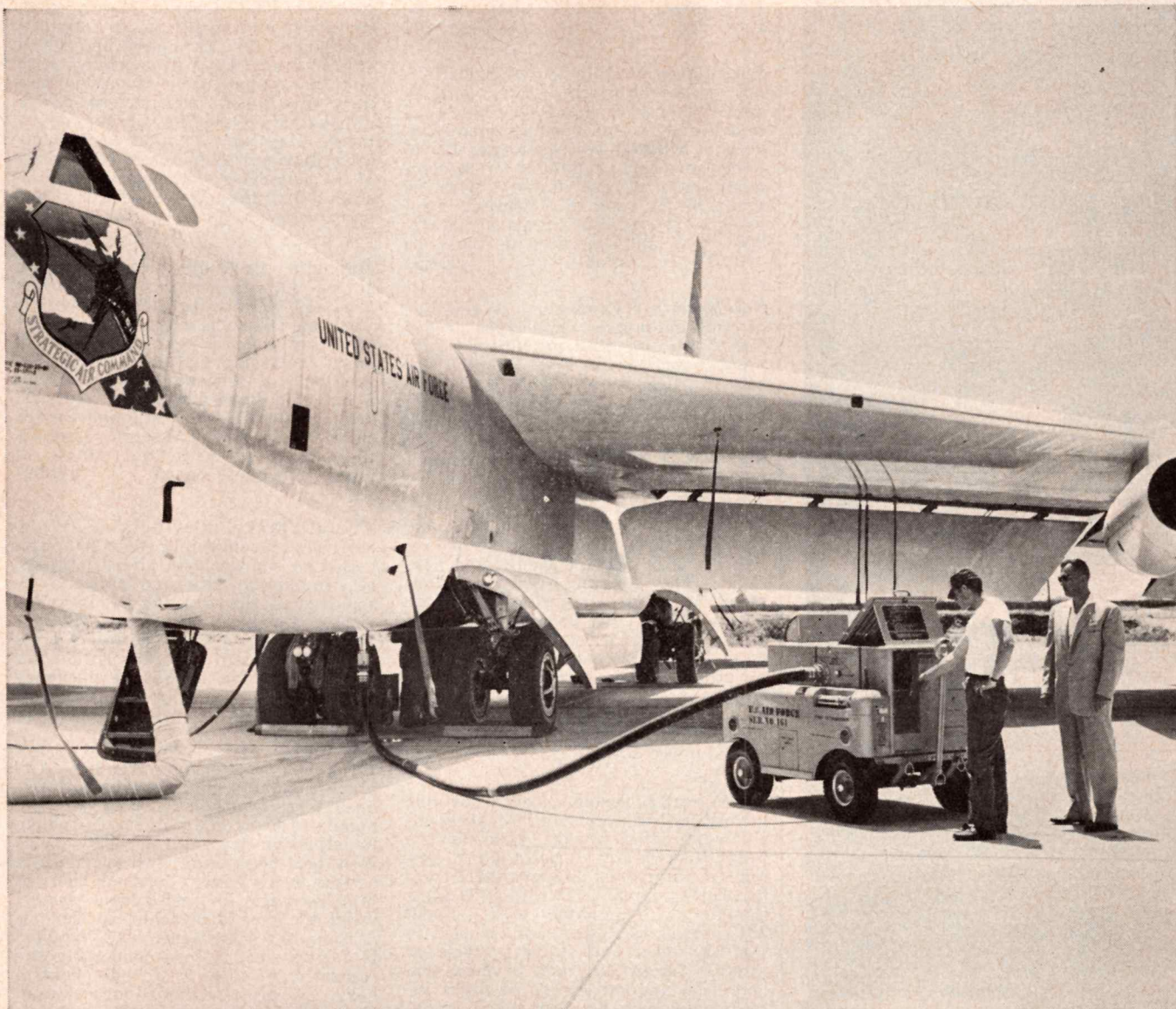
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AERO DIGEST



Mobile gas turbine power cart takes only 30 seconds to start giant B-52 jet engines

The AiResearch MA-1A mobile gas turbine compressor, the first unit of its kind qualified by the Air Force to start the intercontinental B-52 bombers of the Strategic Air Command, is now in volume production at the AiResearch Manufacturing Division of Arizona.

Entirely self-contained, it furnishes a completely automatic source of compressed air power at the point of use. All components, parts and accessories

are included in the fully-enclosed weather-proofed trailer.

The mobile unit weighs only 1150 pounds and may be controlled either from the instrument panel or from a remote control panel. It will start and maintain continuous operation at ambient temperatures ranging from -65°F to 130°F , together with the other extremes of environmental conditions encountered at airports throughout the world.

The two-stage gas turbine compressor may be removed easily from its trailer for use in other vehicles or as a stationary unit. It has an output capacity of 120 pounds per minute flow at 50 psia... enough power to meet all ground service needs for a modern airplane.

Write to our Sales Planning Department for further information on this product.

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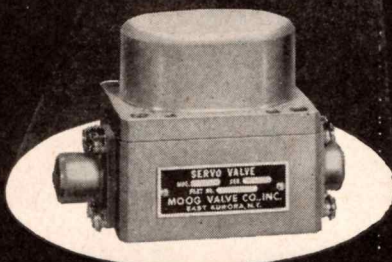
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Designers and manufacturers of aircraft systems and components: REFRIGERATION SYSTEMS • PNEUMATIC VALVES AND CONTROLS • TEMPERATURE CONTROLS

CABIN AIR COMPRESSORS • TURBINE MOTORS • GAS TURBINE ENGINES • CABIN PRESSURE CONTROLS • HEAT TRANSFER EQUIPMENT • ELECTRO-MECHANICAL EQUIPMENT • ELECTRONIC COMPUTERS AND CONTROLS

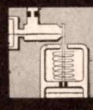
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MOOG
Servo Valves
Deliver
High Dynamic
Performance



Type... 4-way proportional, electro-hydraulic
 Equivalent Time Constant... as low as $1\frac{1}{2}$ milliseconds
 Output Flows... 0.1 to 50.0 GPM
 Control Currents... 2.0 to 40.0 milliamperes
 Pressures... 1000 to 3000 PSI
 Weight... as low as 11 ozs.
 Maximum Dimensions... as low as 3.1" x 2.1" x 1.9"

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MOOG VALVE CO., INC.
 EAST AURORA, N. Y.

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Both metal or molded bases can be furnished. (E-24)

Potentiometer. New series 5600 Helipot Corporation precision potentiometer is a 2 in. diameter, single-turn unit for servo or bushing mounting, with or without ball bearings. Up to 8 sections can be ganged on a common shaft at the factory with as many as 21 taps to a section. Provides total resistance from 35 to 80,000 ohms and linearity as close as $\pm 0.15\%$ is available. (E-25)

Sub-Miniature Connector. A new line of sub-miniature connectors coded "MC," for use with miniature equipment using 5 amperes current per contact, has been added to Cannon Electric Company's connector line. There are two insert sizes in resilient material and eight receptacles and plugs, with 84 different possible connector combinations. (E-26)

Foam-In-Place Potting Compound. Designed to solve shock problems, E-P-Fome is light in weight and non-toxic. The foaming reaction takes place at room temperature without pressure to rapidly produce semi-rigid or rigid foams with controlled densities from 3 to 30 lbs/cu ft. Suggested applications include potting of electrical components and fabrication of raydomes. Electronic Plastics Corp. says it provides continuous service from -80° to 250°F . (E-27)

Pitot-Static Tester. New "portable laboratory" of precision indicating instruments that makes possible the flight line testing of pitot-static systems in aircraft is now available commercially from Aircraft Products Company. Designated APC Model 381 pitot-static tester, unit is used to test the pitot and static systems of aircraft for leakage and to check the operation and calibration of flight instruments such as altimeters, machmeters, and air speed and rate-of-climb indicators. Conforms to MIL-T-8076A. (E-28)

Air Compressor. Development of a new and improved compressed air starter unit, fitted with a Boeing 502-11B gas turbine-powered centrifugal compressor, has been announced by the Industrial Products Division of Boeing Airplane Company. Air horsepower output of the 502-11B is 210, and now output is produced by a single-stage compressor rather than twin-stage. Compressor is used for starting large jet engines and checking out aircraft pneumatic power and air-conditioning systems. (E-29)

Dynamic Force Gages. New series of force gages are available for measurement of dynamic forces in any system or structure. Endevco Corporation report new methods of dynamic testing are made possible by use of this device, which provides voltage output proportional to dynamic force. Applications include testing of plastics for their dynamic properties, measuring dynamic driving forces of electro-dynamic vibration tables and measuring transient shock forces in ejection type mechanisms and shock absorbers. (E-30)

Portable Phase Angle Meter. Self-contained and requiring no auxiliary equipment for its operation, device offers direct way of checking relay and instrument connections, particularly directional over-current relays, differential relays or similar equipment. May also be used to measure prevailing power factor in each phase of a polyphase watt-hour meter installation. Eastern Specialty Company. (E-31)

Magnetic Proximity Switch. New switch with no moving parts, developed at Minneapolis-Honeywell's Doelcam Division, magnetically monitors any assembly-line sequence of parts containing metal. It "confirms" each piece as it comes along and trips a remotely located relay so that part can move on to next station. Switch shuts down whole assembly line if there is a break in the parade of pieces it is checking off. (E-32)

Aircraft Brake. New lightweight aircraft brake, containing some 200 parts less than conventional aircraft brakes of comparable size and capacity, is reported by the Aviation Products Division, Goodyear Tire and Rubber Company. It is claimed brake gives up to 50% more heat absorption per lb by combining disc-brake efficiency with new metallic friction mix lining material. (E-33)

100-Foot Screwdriver. Boeing Airplane Company engineers have developed a screwdriver with a 100-foot handle to overcome a difficult problem in adjusting jet engines. The device is a box containing two electrically driven screwdriver heads which fit into recesses in fuel-control screws when the box is attached to the underside of a jet engine. The "handle" is a long electric cord connecting the screwdriver with a remote control box. Called a remote engine trim actuator, device enables one mechanic in an airplane's cockpit to make precision adjustments on jet engine fuel control during pre-flight operations by operating two toggle switches. (E-34)

Aviation Oil. Gulf Oil Corporation announced plans to market a newly perfected detergent aviation oil for use in all types of aircraft engines. The new Series D is a blend of oils to which has been added an anti-foam agent and a detergent dispersant effective for both high and low temperature operation, according to the manufacturer. Will be made available in three popular viscosity grades. (E-41)

Insulating Blanket. A high temperature insulation blanket of Fiberfrax ceramic fiber, a material that is said to resist temperatures as high as 2300°F , has been introduced by The Carborundum Company. Made of extremely fine, closely intertwining aluminum silicate fibers, the Fiberfrax blanket keeps its form and properties despite elevated temperatures, according to the manufacturer. May be used on gas turbines and as insulation lining in alloy and refractory furnaces. (E-42)

trade literature

You may obtain copies of booklets and pamphlets below by circling the appropriate number on the Reader Reply Card on page 65.

Aircraft Fasteners. 24 pp booklet discusses and illustrates with numerous diagrams and photos what American Screw Company describes as a new concept of fastening for the aviation industry. Called Torq-Set, new fastener is produced from highly alloyed steels and the recessed design permits extremely high driving force without burring or distortion, according to the manufacturer. Company reports average torquing ability of the 9/16 in. Torq-Set is 2540 in.-lb, 58% higher than actual torque requirement. (T-1)

Teflon Products. 12 pp illus brochure describes Chemlon products such as mechanical and hydraulic packings, "O" rings, and electrical/electronic parts and insulation. Includes data on properties, complete specification table and descriptions of fabricated products, together with operational and service data. Crane Packing Co. (T-2)

Extruded Products. 6 pp folder, TB-413, includes a list of the ferrous and non-ferrous alloys which have been successfully extruded into tubing, solids and shapes. Discusses size ranges, dimensional tolerances and diagrammatically explains the Ugine-Sejournet hot extrusion process as used by the Tubular Products Division of The Babcock & Wilcox Company. (T-3)

Resolvers, Servo Amplifiers, Servo Motors. Norden-Ketay bulletin 374 gives specifications and characteristics of 36 precision resolvers available in standard frame sizes 10, 11, 15 and 23. Bulletin 382 gives specifications of 60 cycle and 400 cycle magnetic servo amplifiers. Bulletin 371 gives specifications and gear ratios for gear head servo motors sizes 11, 15 and 18, with low inertia and low backlash. (T-4)

Rivet. 4 pp illus bulletin TCL-112 describes Cherry "700" rivet, listing head styles, diameters and lengths available. Townsend Company. (T-5)

Self-clinching Fasteners. 12 pp illus bulletin CL-356 gives full information on these fasteners. Load carrying threads can be obtained in thin steel, brass, copper or aluminum sheets with Penn Engineering & Mfg. Co. self-clinching nuts. (T-6)

Jet Engine Test Facility. 9 pp Bulletin 5101 presents Baldwin-Lima-Hamilton Corporation's new SR-4 jet engine test facility for remote electri-

cal measurement of thrust. Covers design features in including use of single SR-4 cell of 20,000 or 30,000 lb capacity and incorporation of a calibrating cell. Describes various types of instrumentation for indicating or recording engine thrust, various pressures, and fuel or lubricant flow. (T-7)

Servo Motors and Generators. 16 pp Catalog No. 7 consists of characteristics charts, performance data, dimensional drawings, and complete specifications for the entire G-M Laboratories Inc. line of servo motors and generators. Gives detailed information to enable systems engineer to specify special control phase characteristics for his particular requirements. Charts show effect of winding temperature on stall torque, wiring diagrams, speed torque curves, standard output shafts, and quick cross-reference of SAE and BUORD mo-

tors which are presented in table form. (T-8)

Aluminum Digest. 32-36 pp illus monthly publication containing 50 to 60 reviews of articles relating to aluminum that have been published in the technical press the preceeding 30-60 days is being made available by Reynolds Metal Company. "Reynolds Aluminum Digest" also carries news summary of related current events, statistics on aluminum industry and patent listings. Anyone wishing to receive this publication monthly without charge, circle this reader reply number. (T-9)

Proximity Transducer Systems. 4 pp illus bulletin describes a standard and high sensitivity system. Both systems are capable of sensing operations in excess of 1000/sec and are used with electronic counters, recording devices, batch counters, oscilloscopes and DC



Easy to use as ABC...

- A Mount transducer
- B Connect output to counter, recorder, or control
- C Plug into AC outlet

Automatically
Batch and Count
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626

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WRITE:

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Engineering Personnel
Dept. 991- 9 AD
P.O. Box AN
Bellflower, California

voltmeters. Electro Products Laboratories. (T-10)

Simplified Drafting Practices. 56 pp booklet details American Machine & Foundry Company standards on drafting room practice and simplified drafting procedures and furnishes helpful data on general procedures. Contains speech on this subject given by Jay H. Bergen, AMF Standards Administrator, and gives 11 rules which appeared in his booklet Simplified Drafting. (T-11)

Navigator System. 20 pp illus brochure explains how the Bendix-Decca system works, describes its component units and discusses technical side of the system. According to Pacific Division, Bendix Aviation Corporation, system gives accurate reliable and continuous position fixing for helicopters, fixed wing aircraft, ships and land vehicles, and is ideally suited for terminal area traffic control and landing approach procedures. (T-12)

Resistors Chart. Engineering guide gives comprehensive data on International Resistance Company's complete line of resistors and special products. Includes JAN or MIL equivalent, rated wattage, standard tolerances, temperature rise and coefficient, dimensions and approximate prices. (T-13)

Boring Heads. 12 pp illus catalog 6B covers six standard precision boring heads and a patented adjusting principle for close tolerance boring. Briney Mfg. Co. says the adjusting principle consists of a bushing mounted on pre-loaded ball bearings between the flange and the boring bar. The bushing hole is slightly eccentric with its outside diameter, providing an adjusting range for the boring bar of 0.012 in. on diameter. (T-14)

Vulcanized Fiber and Laminated Plastics. 4 pp illus bulletin entitled "Engineering Materials to Improve the Design and Performance of Your Product" is announced by National Vulcanized Fiber Co. Describes physical properties and industrial uses of vulcanized fiber and Phenolite laminated plastic. (T-15)

Circuit Analyzers. 6 pp illus brochure describes Dit-MCO, Inc. model 80 circuit analyzer. Model 200 universal, automatic, electrical circuit analyzer is discussed, with specifications and method of construction diagram in another Dit-MCO, Inc. 6 pp bulletin. 4 pp folder covers Model 144 NX universal, automatic circuit analyzer for military use. (T-16)

Electrical Indicating Instruments and Test Equipment. 87 pp illus Technical Manual 17 describes complete line of Simpson Electric Company and in-

cludes wiring diagrams and dimensional drawings. Panel meter section shows more than 800 different kinds and sizes of panel meters which company carries. (T-17)

Leak Detector. 6 pp illus bulletin 483 contains technical data and application information on Beckman Instruments, Inc. leak detector, which was designed to locate minute leaks in pressure, vacuum and hermetically sealed systems and units. (T-18)

Fastening Device. 4 pp illus folder introduces new fastening device called "Spherelock," which consists of an insert and mating screw. Bellford Metal Products, Inc. says "Spherelock" presents many possibilities as a substitute for such conventional staking or fastening devices as nuts, bolts and cotter pins used in assemblies. (T-19)

Steel Tolerance Tables Chart. New tolerance tables and additional size ranges for square, rectangular and round carbon and stainless steel welded Electrunite mechanical tubing are described in handy reference data published by Steel and Tubes Division of Republic Steel. Wall and cut length tolerances for hot and cold rolled carbon and stainless steel tubes, chemical analyses and weight, and physical properties are contained in mounted charts and also pocket-size booklet. Please indicate choice of chart or pocket-size data. (T-20)

Aircraft Aluminum Extrusions. Pioneer Aluminum Supply Company catalog features cross-reference section which relates the extrusion die numbers of 23 major airframe manufacturers, plus Alcoa, to an Army-Navy Drawing or Pioneer Aluminum stock number. Over 2000 different extruded shapes are included. (T-21)

Remote Directional Gyroscope. General Electric Company data sheet 8327 gives application, features, specifications and description of Type 8KD3 directional gyroscope, designed primarily for use with the MA-1 Compass System for the Bureau of Aeronautics, USN. (T-22)

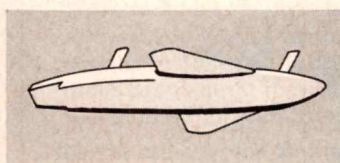
Titanium. 6 pp illus paper on "The Drawing of Titanium," by James S. Kirkpatrick, V.P.—Research & Development, Brooks & Perkins, Inc., discusses techniques for drawing and other forming methods. Paper was presented at annual meeting of ASTE. (T-23)

Bearings. 52 pp illus "E-56 Engineering Manual" includes data on properties of Oilite materials and lists Brinell and Rockwell ratings for Oilite materials. Special 12-page insert lists over 1000 standard Oilite sleeve, flange and thrust bearings, cored, solid bar and plate stock available

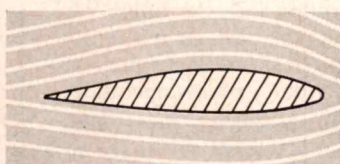


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Now even the ice- and snow-covered Arctic regions present no landing problems to aircraft whose design includes the Pantobase landing system. A product of Stroukoff research and development, Pantobase will permit landings and take-offs from snow, ice, sand, water and unimproved terrain, thereby extending the operational capabilities of the aircraft and reducing the need for conventional airports in many remote and previously inaccessible parts of the earth's surface.



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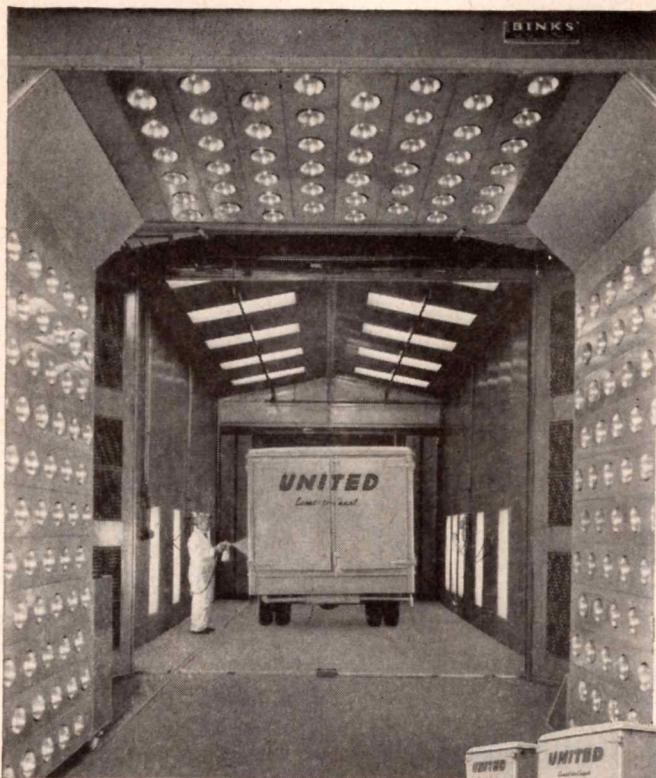
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How time was saved...based upon previous experience, Mr. Lantz recommended the installation of Binks equipment and called in Binks engineers for consultation. A Binks "drive-thru" spray booth and drying oven were installed to produce factory quality, dust-free finishes...

quickly dried to a mirror-like hardness. This set-up accommodates the largest trucks or several units of small equipment. A climate-controlling filtered air supply system was also installed in the shop to replace the air exhausted through the booth and to prevent dust infiltration.

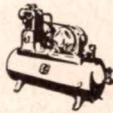
How space was saved...the drying oven was placed on tracks so it could be rolled into the booth for finish drying or storage when not in use. Electrical interlocks prevent accidental simultaneous operation.

Engineering assistance—yours without obligation...over 60 years of unmatched experience in the manufacture and application of spray painting equipment is ready to serve you. Call your nearest Binks office or write to the address below:

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from Amplex Division of Chrysler Corporation. (T-24)

Alloy Steel Tubing. 4 pp folder TDC-184 presents technical information on 12 of the most widely used "4100 series" of alloy steels. Includes data on carburizing and thermal treatments, critical points, mechanical properties and suggestions on welding and machining of these steels. Tubular Products Division of The Babcock & Wilcox Company. (T-25)

Air Control Valves. 72 pp catalog illustrates entire line of 2-, 3- and 4-way air control valves available from Airmatic Valve, Inc. Each type valve, cylinder and strainer is handled separately, and information on its features, application, dimensions, specifications and parts list breakdown is provided. (T-26)

Potentiometers. 20 pp illus catalog gives detailed description, technical data, dimensional drawings, specification alternates and power rating curves of the precision potentiometers offered by The Gamewell Company. (T-27)

Engineering Data Wall Chart. Features tables on decimal equivalents, temperature conversion, wire size and current ratings, and mechanical and electrical conversions. Perkin Engineering Corporation. (T-28)

Fluorocarbon Products. 8 pp illus brochure describes forms, properties and uses of a wide range of fluorocarbon products—from plastic resins to acids and dielectric fluids—offered by The M. W. Kellogg Company. (T-29)

Test Laboratory Facilities. 72 pp illus bulletin outlines services and facilities of Electrical Testing Laboratories, Inc. Covers typical measurements and determinations made on hundreds of products and materials. Catalogues laboratory equipment available for testing, applied research and engineering analysis. (T-30)

Aircraft Switches. 4 pp illus bulletin describes propeller feathering system switches, turbojet engine starting system switches and generator and inverter circuit switches available from Airite Products, Inc. (T-31)

Temperature Probe. Rosemount Engineering Co. brochure discusses a new total temperature probe, meeting critical accuracy requirements of outside air measurement in supersonic aircraft applications up to Mach 3 and beyond. The company reports that an outstanding characteristic of the probe, Model 101U, is its 50 ohm platinum resistance thermometer element that is hermetically sealed without sacrificing the very low time constant. (T-33)

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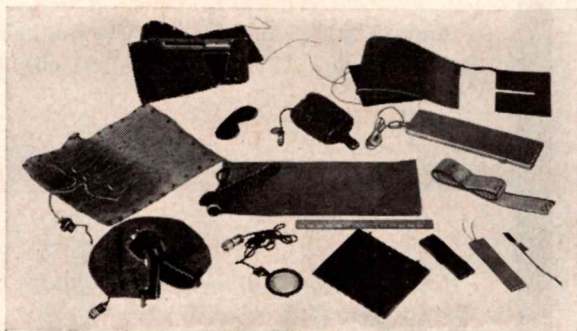
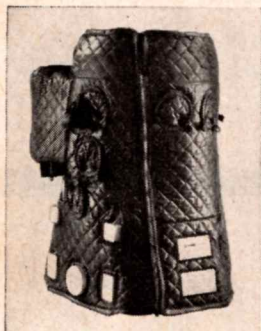
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SEPTEMBER 1956



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Inorganic Pigments. Chart folder illustrates colors of inorganic pigments manufactured by the Color Division, Ferro Corporation. Data and specifications include specific gravity, bulk density fineness residue on 325 mesh screen, oil absorption and composition. (T-34)

Instrumentation. 4 pp bulletin presents new approach to recording, indicating and controlling instruments required in industrial processing. Interchangeable components perform a variety of functions, minimize maintenance problems, according to Fielden Instrument Division, Robertshaw-Fulton Controls Company. (T-35)

Low Torque Gauges. 4 pp bulletin describes six models of Torque-Watch dial reading gauges that measure extremely low torque on such devices as potentiometers, servo mechanisms, spring mechanisms, gear trains, magnetic clutches and small motors. Waters Manufacturing, Inc. (T-36)

Liquid Level Sensing System. 8 pp booklet, AD-404, describes system capable of operating a lamp to indicate that gasoline, oil or other liquid is above or below a certain level and to provide control to start and stop pumps or operate valves to transfer liquid from one tank to another. Simmonds Aerocessories, Inc. (T-37)

Total Radiation Pyrometers. 8 pp paper describes two new pyrometers combining good spectral response, high sensitivity, rapid response, stability and accuracy. Servo Corporation of America. (T-38)

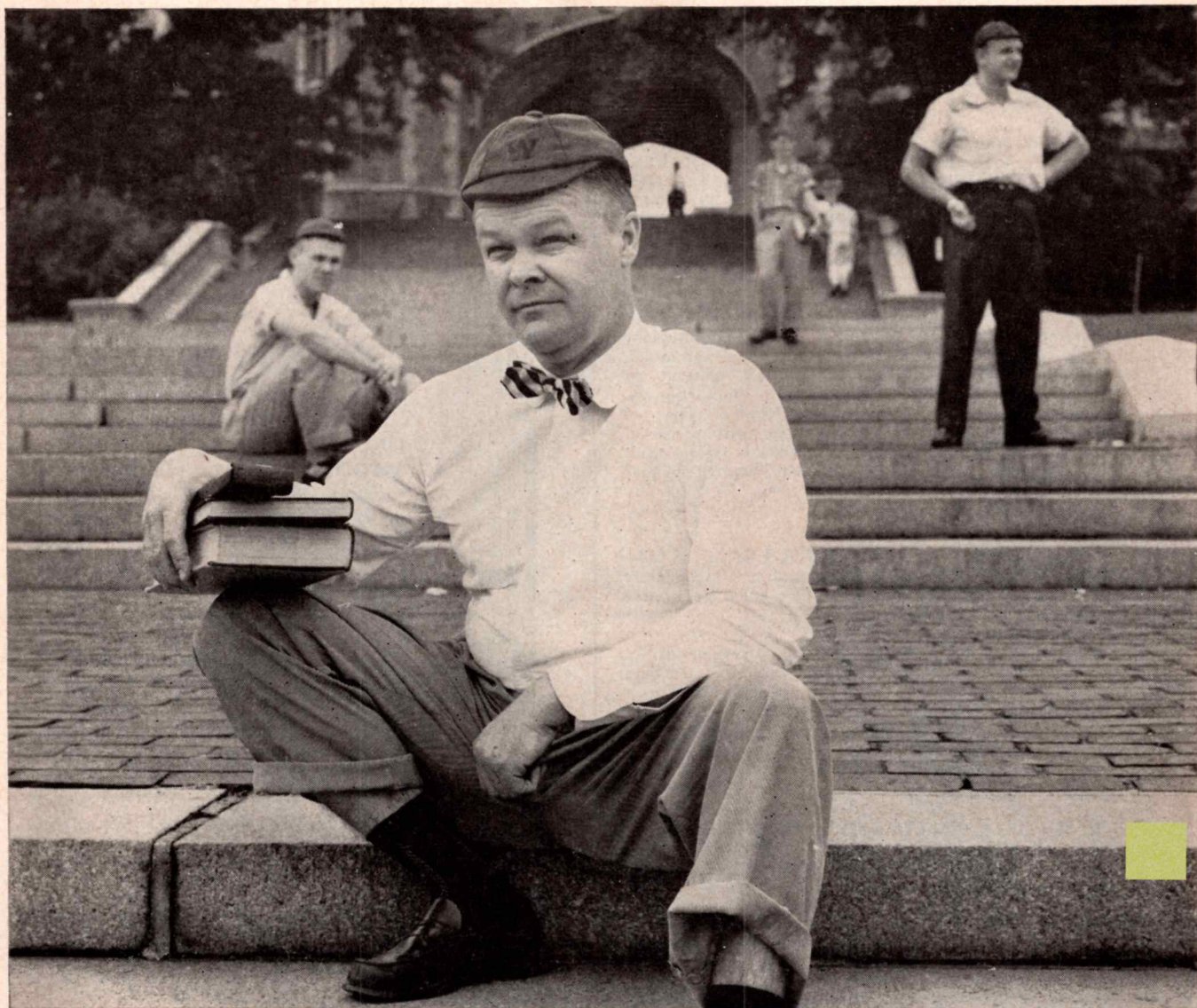
High Temperature Alloy. Booklet discusses Hastelloy alloy R-235, a wrought, nickel, base, aluminum and titanium bearing, precipitation hardening alloy with outstanding properties through 1750° F, according to Haynes Stellite Company. (T-39)

Fractional HP Motor Selector Chart. Lists characteristics and performance ranges of all fractional hp motor types, plus speed torque curves for basic motor types. Howard Industries, Inc. (T-40)

Radial Engine Suspensions. Technical bulletin lists engines on which Lord Dynafocal Radial Engine Suspensions are applicable and explains the vibration isolation principle. Lord Manufacturing Company. (T-41)

Silicone Rubber Stocks. 8 pp illus brochure describes properties and applications for Silastic 50 and 80, general purpose silicone rubber stocks manufactured by Dow Corning Corporation. (T-42)

Overhead Materials Handling Systems. Illus booklet No. 2008-M covers carriers for hand, electric and automatic operation; tractors; track switches; standard cranes, transfer cranes and gantry cranes; safety electrification; buckets and grabs. The Cleveland Crane & Engineering Co. (T-43)



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abstracts

Howard J. Curfman, Jr., THEORETICAL AND ANALOG STUDIES OF THE EFFECTS OF NONLINEAR STABILITY DERIVATIVES ON THE LONGITUDINAL MOTIONS OF AN AIRCRAFT IN RESPONSE TO STEP CONTROL DEFLECTIONS AND TO THE INFLUENCE OF PROPORTIONAL AUTOMATIC CONTROL, NACA Rept. 1241, (supersedes RM L50L11), 1955.

Through theoretical and analog results the effects of two nonlinear stability derivatives on the longitudinal motions of an aircraft have been investigated. Nonlinear functions of pitching-moment and lift coefficients with angle of attack were considered. Analog results of aircraft motions in response to step elevator deflections and to the action of the proportional control systems are presented. The occurrence of continuous hunting oscillations was predicted and demonstrated for the attitude stabilization system with proportional control for certain nonlinear pitching-moment variations and autopilot adjustments.

H. Söhngen, STROMUNG VOR EINEM UBERSCHALL-LAUFRAD, DVL Bericht Nr. 11, December 1955. West German Press, (22a) OPLADEN/RHLD, West Germany, price: 7.60 DM. (In German)

The subject of investigation is the flow in front of an ultrasonic axial compressor, which consists of a single turbine wheel that is subject to a flow at ultrasonic speed. For a simple model, one must take into consideration the reflections on the intake from the disturbances originating from the wheel and the modifications which are therefore necessary in the flow around the blades.

Harry H. Heyson, ANALYSIS AND COMPARISON WITH THEORY OF FLOW-FIELD MEASUREMENTS NEAR A LIFTING ROTOR IN THE LANGLEY FULL-SCALE TUNNEL, NACA TN 3691, April 1956.

Measurements of stream angles and velocities were made in several planes both near and behind a single rotor in four different flight conditions in the Langley full-scale tunnel. These measurements indicate that available theory may be used to calculate with reasonable accuracy the induced flow over the forward three-quarters of the disk for these flight conditions if the rotor disk-load distribution is accounted for. Rearward of this point, calculations of the induced velocity are increasingly inaccurate due to the rolling up of the trailing-vortex system. Farther rearward, well behind the rotor, the flow may be represented more accurately by the flow behind a uniformly loaded wing.

C. Dewey Havill and L. Stewart Rolls, A SONIC-FLOW ORIFICE PROBE FOR THE IN-FLIGHT MEASUREMENT OF TEMPERATURE PROFILES OF A JET ENGINE EXHAUST WITH AFTERBURNING, NACA TN 3714, May 1956.

A temperature-measuring system using two sonic-flow orifices in series is described. This system was adapted to measure the exhaust gas temperature of an afterburning jet engine and was mounted in a swinging pitot-static probe. The sonic-flow orifice system had only a small variation in temperature at the thermocouple and temperature change was measured as a change in pressure. Measurement of exhaust temperature of 3200° R was obtained during afterburner operation in flight.

Donald E. Swarts and Milton Orchin, VAPOR-PHASE OXIDATION AND SPONTANEOUS IGNITION—CORRELATION AND EFFECT OF VARIABLES, NACA TN 3579, April 1956.

The spontaneous ignition temperatures of eight structurally different hydrocarbons were determined and correlated with the behavior of the same hydrocarbons toward vapor-phase oxidation. Since good correlation of the two phenomena was obtained, it is likely that similar oxidative mechanisms are operative in both.

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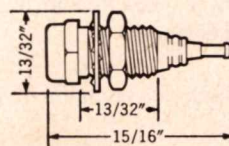
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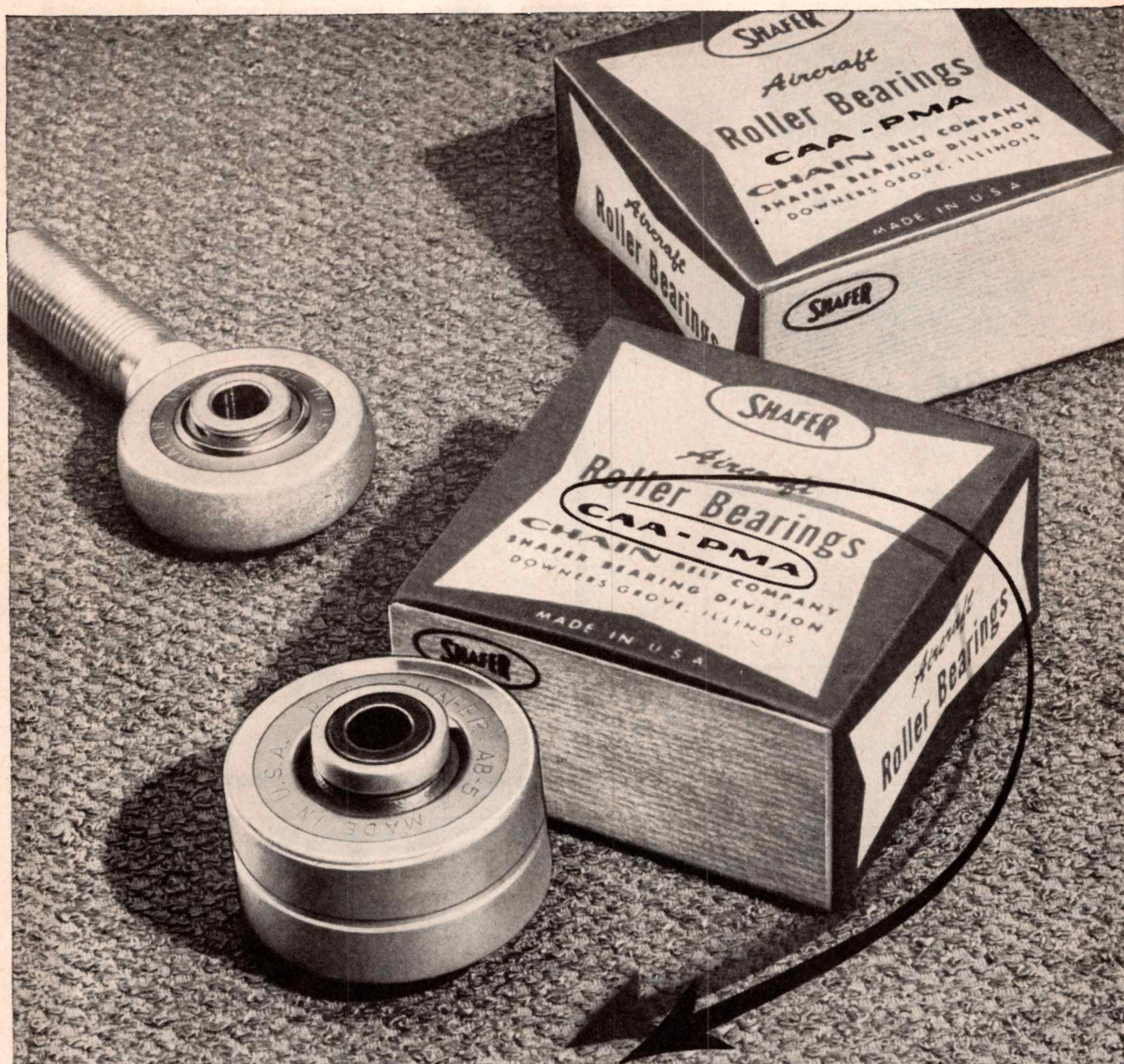
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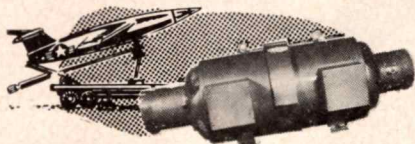
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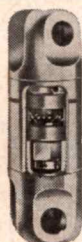
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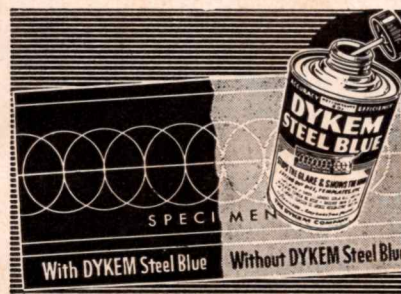
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CAN TIME CLOCKS BE WRONG?

THIS MORNING the time clock was fast. I know this is true because I checked it against my watch, which I had set earlier according to radio time. After I punched in, I spoke to my friend Mooney about the clock. Mooney is a stress analyst, and a person more addicted to keeping records and remembering details is hard to meet. He agreed that the time clock was off. "In fact," he said, "it's been a minute-and-a-half fast all week."

I was dialing the telephone company for the time when Todd came by to check some figures on the new canopy design. Some inconsistencies developed which took us all lunch hour to straighten out. Meanwhile, I took a few minutes to run down for sandwiches for the boys, and on my way back made a small detour to the time clock to make a second check against my watch. Unhappily, I had forgotten to wind my watch the night before and it had stopped.

After we finished eating and had disposed of Todd's problem, I got the time from the telephone company and set my watch. I compared the time with that of the time clock's and found them the same. Sadly I reported my findings to the group, which had been joined by Hale, one of the mathematicians. "How do you know that the clock didn't slow down?" Hale said.

"I don't," I answered, "but is it usual for time clocks to do that? I thought they were pretty foolproof mechanisms."

"That's what you're supposed to think," said Hale, who's somewhat of a radical. "Otherwise the system wouldn't work. But did you ever notice how much later it is when the clock says 5:00?"

"Why yes," I said, "now that you bring it up."

"Therefore," concluded Hale in his best analytic tone, "if the time clock is fast in the morning and slow at night, there must be at least one time during the day when the clock is right. You can take that as a theorem."

Hale left then, and he may have been right, but I couldn't admit it to myself even if he were. I had been punching time clocks for too many years to begin doubting them now. Once in a great while they might be off, but not consistently. I wasn't even going to check again. At least that was my intention until Mooney came up to me later in the afternoon and handed me some more data on the canopy. "By the way," he said, "I've been talking to Todd about this time clock business, and he tends to agree with Hale. I told him I'd see if you've made any more runs on it."

"I wasn't going to," I admitted. "But if you boys think its worth while . . ."

"Worth while!" said Mooney. "Can you think of

anything more worth while than being sure the company and its employees get a fair shake?"

I was convinced, and Mooney and I went out to time the time clock. It was in full agreement with my watch. "Well," I said, feeling that a load had been lifted from my back, "that takes care of that. My watch must've been wrong this morning."

"I don't know," Mooney said slowly. "Incidentally, did you ever work in a place that didn't have time clocks?"

"Are there such places?" I said.

"It's a funny thing about them," said Mooney, "but you find yourself in a different frame of mind. When a company begins thinking that the job you're doing is more important than the time between punches, you start believing it. It's a mutual trust arrangement. You start putting a little more time in to finish the job, and then a little more—sort of a moral obligation." Hale got out of his dreamy mood in a moment. "Punching a time clock isn't what I object to. It's the attitude that gets me—the time-clock philosophy. For instance, I hired out to one firm that told me they didn't believe in time clocks. I was delighted. But when I reported to work, I found myself at the end of a familiar line. When I reached the place where a time clock should have been, I was handed a pen by a guard who told me to sign my name and record the time. In effect, the time clocks were still there because the company was still taking the attitude that their professional employees were not to be trusted to put in a forty-hour week."

I spent the rest of the afternoon working on my design problem. About ten minutes before quitting time, just when the engineers were beginning to queue up in front of the time clock, I received a memorandum from the front office. Subject: Time clocks. It was a long memorandum which in essence said that the company considered its engineers and scientists as its most valuable assets, and that henceforth they will be accorded full professional privileges. Starting the next day, time clocks for this class of employees were to be abolished.

The next morning I got up earlier than usual. My wife thought I was crazy, but I wanted to enjoy the luxury of not punching in. Besides, there was that canopy job that had to be done. As I entered the plant I looked at my watch, which showed me to be a half-hour early, and walked into the design room to wait for Mooney. He was there already, and I went up to him and said, "Mooney, could you tell me the time? My watch seems to have stopped."

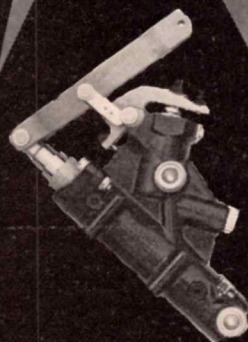
"Mine did too," said Mooney. "Maybe it'll stay that way."

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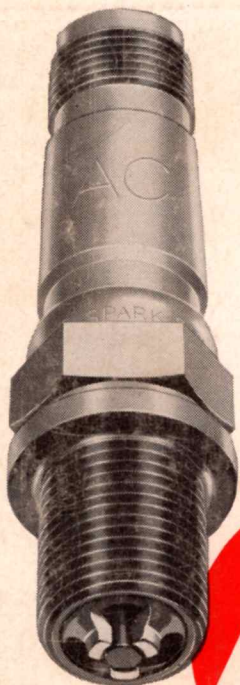
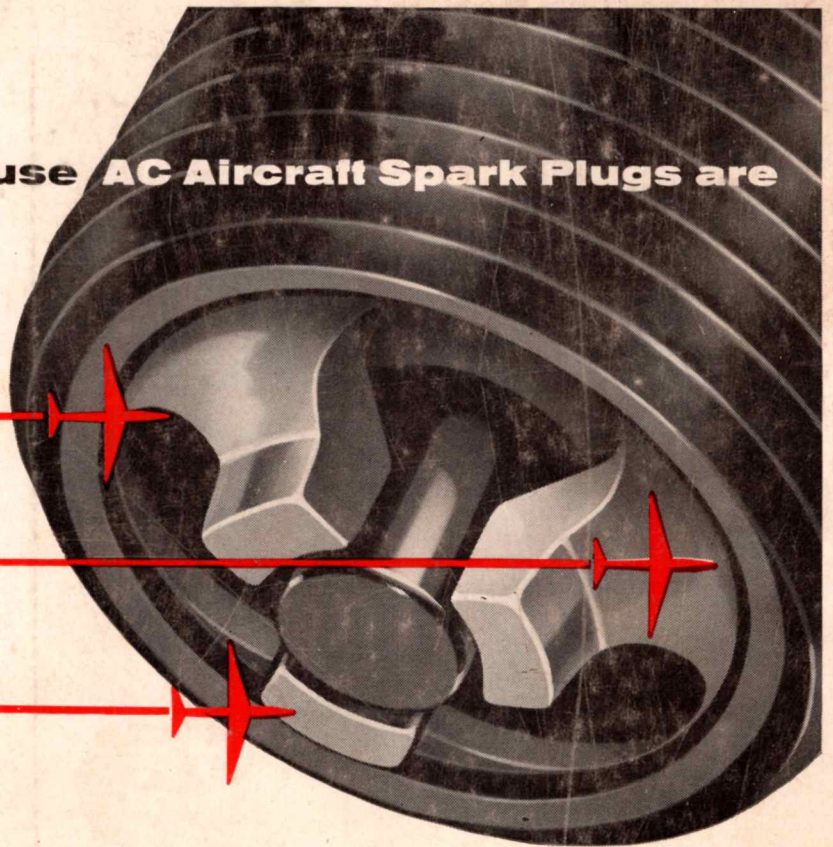
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